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ALOHA NOISE AND PROPAGATION LOSS MEASUREMENTS

SUMMARY

Two measurement programs have been carried out in the Honolulu urban area on the UHF radio channels used by THE ALOHA SYSTEM. The first program involved the measurement of impulse noise in the channel due to automobile ignition noise sources. The second program was directed toward measurement of propagation loss versus range from the central ALOHA SYSTEM transmitter for different urban areas surrounding the central transmitting site. The results of the noise measurements indicated that automobile ignition could have a marked effect on throughput to a packet radio terminal using an omnidirectional antenna in the vicinity of busy streets. The propagation loss maasurements were found to be generally in agreement with those predicted by Y. Okumura, et al., [1], except that the loss measured by ALOHA was lower than that predicted by Okumura.

PART 1 ALOHA IMPULSE NOISE MEASUREMENTS

INTRODUCTION

The effects of radio noise on the performance of the ALOHA channel have been of concern since early in the life of the project. Of particular concern has been the effect of impulse noise on wideband UHF channels such as those utilized in the operating ALOHA SYSTEM. The purpose of this note is to describe an impulse noise measurement program initiated by THE ALOHA SYSTEM Project and to present the results of analysis of the collected data.

Radio systems using nonlinear modulation techniques, such as frequency modulation, have the ability to suppress weaker signals when two or more signals are present simultaneously at the receiver's detector. This ability to suppress a weaker signal is known as the capture effect wherein the strongest signal "captures" the receiver. In general, a strong-signal to weak-signal power ratio of about 3 dB is required to significantly suppress the weaker signal. This is known as the capture ratio. Some FM receivers, working with high-modulation-index signals, have a capture ratio of less than 1 dB. However, this capability does not apply to FSK data modulation since efficient use of bandwidth precludes a large modulation index.

The capture effect can be used in the ALOHA channel to suppress noise impulses when a desired signal is being received. (THE ALOHA SYSTEM uses FM radios.) Gaussian channel noise is not considered an important factor here, since the receiver is considered to be operating above threshold on the desired signal. What is of concern is the peak power density of a noise impulse and the frequency of occurrence of noise impulses with peak power densities equal to or greater than some given power density level. As long as the power density of an impulse is below that of the desired signal by 3 dB or greater, the impulse should not appreciably affect the output of the FM discriminator. If the power associated with received noise impulses were known, and the expected frequency of occurrence of such noise impulses were known, predictions could be made as to how frequently a given receiver would experience capture from noise impulses while receiving a desired signal at a known power level.

Measurements of a given receiver-modem combination could be made to determine the effect of the ratio of impulse-power-to-desired-signal-power on error rate. Thus predictions could be made of the expected error rates for given receiver impulse-noise environments.

The impulse noise measurement program was directed toward gathering impulse noise statistics in an urban environment. From the literature, it is known that impulse noise is densest in urban areas and is predominantly man-made. Of the man-made noise sources, automotive traffic ignition noise is the major contributor. Thus the measurement program was directed toward accumulation of data on ignition noise in an urban area. All the data has been gathered in the form of arrival rates of impulses exceeding given power density thresholds. The measurements were conducted at a ratio frequency of 410 MHZ using a receiver with an effective bandwidth of 0.75 MHZ. The measurement program, instrumentation, analysis and results, and conclusions are set forth in the following sections.

MEASUREMENT PROGRAM

A survey of the literature revealed that little data is available on impulse noise statistics at UHF. Therefore a data collection program was devised which would provide statistics in a form applicable to the burst communication ALOHA channel. Since probability of interference with data packets is related to arrival rate of noise impulses at various power levels, the data was gathered in the form of average arrival rates of impulses with power levels exceeding pre-determined power thresholds. These measurements were carried out for various automobile traffic conditions and locations, in order to obtain typical impulse data. From the data, curves were plotted for the various traffic conditions and locations, relating average impulse arrival rates to power threshold levels. The data was collected in the form of 50-second and 100-second interval samples, the samples being continuously recorded over time periods of hours and days. The longer data collection periods allowed the observation of slow variations in average arrival rates in order to reveal possible long-period cyclic variations in pulse rate density.

In addition to the longer interval samples, some data was obtained using a measurement period of one second per sample. These shorter samples were used to study rapid impulse rate variations for various traffic conditions and to provide pulse rate distributions over short periods of time. Of interest

are the most probable pulse rate, the average pulse rate, the mean deviation from the average, and the shape of the frequency distribution. These data samples were obtained on a "snapshot" basis for durations not exceeding one hour at selected periods of a day.

Two types of traffic locations were measured. They were:

(a) a busy intersection

(b) a cross-section of a freeway

The traffic at the intersection was measured during the daytime period of 8:00 AM to 5:00 PM. The traffic on the freeway was measured on a round-the-clock basis for four days. Table 1.1 lists the data files collected on the two locations. The busy intersection selected was the main entrance to the University of Hawaii, the intersection of Dole Street with East-West Road. The freeway measurements were made on the Lunalilo Freeway near the University interchange. This freeway is a six-lane arterial which threads through the center of Honolulu and carries a high volume of traffic. The two locations were selected as quite dissimilar since the intersection is characterized by waiting line traffic at the traffic light and the freeway is characterized by freely flowing traffic. Therefore, large numbers of stationary vehicles can be exposed to the antenna for lengthy time periods at the intersection while individual emitters have only a short exposure time on the freeway even though numbers of vehicles passing per second can be large.

Measurements were made for three or four different power thresholds, spaced 6 dB apart. A larger number of thresholds spaced at closer intervals would have been desirable, but practical limitations on resources precluded finer resolution in the measurements. As is apparent in Table 1.1, measurements at the various threshold levels were made sequentially, another limitation to the experiment. Limitations in available equipment allowed only one threshold measurement at a time. It would be much more desirable to perform the several threshold measurements simultaneously in order to remove the effects of time variations of traffic density. The effects of these time variations were apparent in the collected data, and tended to degrade the data analysis. However, the long-period variations of freeway traffic seemed reasonably dependable, allowing some correlations to be made on a day-to-day basis.

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INSTRUMENTATION

The equipment setup for gathering the impulse data is shown in Figure 1.1. A Yagi antenna with 10 dBd gain was used to localize the measured source and provide additional gain to overcome the receiver's internal noise. This antenna has a horizontal beamwidth of 60 degrees and a vertical beamwidth of 40 degrees when oriented for vertical polarization. Sidelobes are at least 13 dB down from the main lobe so that good directivity is achieved. For the freeway measurement, the antenna was aimed perpendicular to the direction of the freeway. For the measurement of the intersection, the antenna was aimed at the intersection, making a sharp angle with East-West Road.

The receiver used is part of an AN/URM-17 Radio Test Set, specially designed for radio interference measurements. When tuned to 410 MHZ it has an effective bandwidth of 0.75 MHZ. The receiver was set up for measurement of effective peak values of impulse interference. A slideback circuit sets up an effective peak power threshold in the receiver's detector. Any impulses exceeding this threshold are detected and fed to a pulse-stretching circuit, the output of which is fed to the audio output of the receiver. This audio output is in turn fed to an ALOHA-designed threshold detector circuit which converts the impulse to a standard TTL-level pulse which in turn is fed to the Data Acquisition System. Measurements have shown that impulses exceeding the receiver's threshold level by one dB or greater will be detected with practically 100 per cent probability.

The Data Acquisition System consists of a pulse rate integrator and a paper-tape-punch recorder. The pulse rate integrator is set to count the number of pulses occurring in a preset interval. At the end of the interval the accumulated count is sent to the tape punch which records it on eight-level punched tape in ASCII code. After recording the data, the counter resets to zero and begins a new count. This process is repeated continuously during the entire data measurement period. The capacity of the data accumulator is 9,999 counts. When pulse rates were encountered that overflowed the accumulator, the measurement period was shortened to insure non-ambiguous measurements. This condition was encountered at low threshold levels during peak traffic periods using a 100-second count interval. Thus, measurements of heavy traffic conditions used 50-second counting intervals. It is desirable to use as long an interval as possible, in order to reduce the computing load when the data is processed.

As mentioned in the introductory section, one-second samples were recorded on a limited basis in order to collect information on rapid pulse rate variations. Since large numbers of samples are generated during relatively short measurement periods, this data accumulation approach was used on a "snapshot" basis to provide detailed data during characteristically high-traffic density periods. The measurement periods were limited to not more than one-hour durations.

In order to determine equivalent source levels of measured impulses, a path-loss measurement was performed for each location. A signal generator was connected to the antenna cable at the connector ordinarily attached to the receiver input. With a 0 dBm source level from the signal generator at 410 MHZ, a calibrated 0 dBd gain dipole antenna coupled to a Tektronix Type 1401A/324 portable spectrum analyzer was used to measure the received signal level at the anticipated source location. The analyzer's built-in calibrator (accuracy of 0.5 dB) was used to ensure accurate readings. The freeway measurement was made from a vehicle travelling in the near-lane past the antenna location. Several passes were made and the average of the maximum readings recorded was used to determine the loss measurement. The intersection measurement turned out to be somewhat trickier since East-West Road made a sharp angle with the directional axis of the Yagi antenna. Thus, the maximum reading was not on-axis with the antenna but at a point about 50 feet back from the intersection along East-West Road. The difference in levels between this point and the on-axis point at the intersection is about 12 dB. Since some preliminary data was released with incorrectly calibrated levels, the threshold levels indicated in this preliminary data should be reduced by 12 dB. However, all levels provided in this note are correct. Table II relates receiver threshold levels to source threshold levels.

ANALYSIS AND RESULTS

The punched-tape data records shown in Table 1.1 were read into the University of Hawaii System 360/65 computer and stored on disk files. All data was processed by programs written in PL/I language. Processing was performed via the time-sharing system using the ALOHA random access radio channel to access the computer from an ALOHA terminal. Four short programs were written to provide statistics of interest and a rudimentary time-series analysis of pulse arrival rate. Copies of these programs are contained in the appendix. Program STAT 1

computes the various statistics summarized in Table 1.3. Programs SORT 1 and SORT 2 compute frequency distributions and cumulative distributions of pulse arrival rates for each data record. Program PLOT computes the averages of consecutive groups of samples in a record and plots these averages sequentially to provide a time series of averaged pulse arrival rate.

DISTRIBUTIONS

In addition to the statistical summary presented in Table 1.3, another summary is presented in Table 1.4, which enables one to relate the most important statistics to the sample period, threshold level, source location, and time of measurement. By referring to Tables 1.3 and 1.4, some relationships become evident. For example, as the mean values decrease, the standard deviations do not decrease proportionately, indicating a shift from a distribution balanced about the mean to one which is highly skewed. Actual plots of some computed frequency distributions, shown in Figure 1.2, show this to be the case. Although these distributions appear to be Poisson, a chi-square test indicates a poor fit of the data to a Poisson distribution. Thus we can only guess that the underlying impulse-generating process is Poisson and conclude at this time that we have a highly skewed distribution of some sort.

Figure 1.3 also provides some insight into the stability of the impulse-generating process. Visually, it appears that the distribution remains the same from day to day although the mean arrival rate of impulses changes, probably due to changes in average traffic volume.

If cumulative distributions of the one-second sample records are computed for the case of -19.7 dBm/MHZ threshold level, the resulting data plots appear as shown in Figure 1.4. The probable average pulse rates tend to be lower for the freeway data (curves A and B) than for the intersection data (curves C and D). The result may be due to the antenna beam pattern "seeing" fewer numbers of vehicles at a time for the case of freeway measurements than for the case of intersection measurements. Because of the sharp angle made between the antenna and East-West Road, the antenna beam pattern covers a large area of this street back from the intersection and thus "sees" relatively large numbers of vehicles within the antenna aperature whenever they are queued up at the traffic light. The comparable situation exists on the freeway when traffic volume becomes so dense that average vehicle speed is reduced to allow longer

exposure times to the antenna. This case appears to occur during the morning rush hour, but no one-second samples were collected for this period which would allow a comparison to be made. In any event, greater numbers of sources tend to increase the average pulse counts.

TIME VARIATIONS

Some calculations were made to allow examination of changes in average impulse rates with time. For the freeway data, 30 minute averages were plotted against time for 24 hour periods at four different threshold levels. The results are shown in Figures 1.5 through 1.8. As can be seen in the figures, impulse rate peaks during the morning rush hour of 7-8 AM. A broader, lower maximum occurs between 3 and 4 PM and then the average rate drops off to a very low minimum between 2:30 and 3:30 AM. This cycle repeats quite consistently from day to day.

Measurements of intersection traffic did not cover the 24 hour time spans used for freeway measurements and as such do not easily lend themselves to comparison. However, the 8 AM to 5PM duration of these measurements has been compared to the same time interval of the freeway traffic. During this period, the average pulse arrival rate from the intersection traffic shows little tendency to peak at any particular time of day. A somewhat higher variability indicates more rapid fluctuations in the intersection traffic than the freeway traffic. The average impulse arrival rates tend to be higher for the intersection traffic.

PULSE POWER DISTRIBUTIONS

Of greatest interest to this study is the relationship between average pulse arrival rate and radiated pulse power. Measurements of average impulse arrival rates for power levels above given thresholds were plotted for different traffic conditions and time periods for the freeway data. For the intersection data, the 8 AM - 5 PM average values were similarly plotted and compared to like time-period data from the freeway measurements. These plots are shown in Figures 1.9 and 1.10, respectively. These curves describe cumulative distributions since they are for average pulse rates equalling or exceeding given power thresholds. Curve A is a least-squares straight-line fit to the data, whereas the other curves are drawn to show the apparent change in slope with increasing power thresholds. The equation for curve A is shown in Figure

1.9, whereas no equations have been derived for the other curves. However they appear to have an exponential form with curve A forming a limiting case under heavy traffic conditions. If the cumulative distribution is assumed to be exponential in form, then it would seem reasonable to expect the underlying frequency distribution to also have an exponential form. More measurements will be needed to improve confidence in these results.

From the curves plotted on the freeway data, a wide range of pulse arrival rates can be seen to occur as a function of traffic conditions. For a quiet period, such as shown by curve E of Figure 1.9, pulse arrival rates at the lowest threshold do not exceed the rate recorded for busy-hour traffic at the highest threshold. Day-to-day variations are also apparent in the intersection data recorded at the same threshold, as shown in Figure 1.3.

In general, the mean pulse arrival rates at low threshold levels tend to be larger for short sampling periods than for longer sampling periods (see Table 1.4). The highest rate recorded was at the intersection during the 4:00-5:00 PM busy hour. This 65.5 pps rate, although twice that of the nine-hour average, seems indicative of an upper limit at this threshold level for heavy traffic conditions. Because of the skewed distribution of arrival rates for this case (see Figure 1.11) the most probable arrival rate is well below the measured average. Of greater interest however is the tendency of short interval measurements to merge with long-interval measurements at higher thresholds (see Table 1.4). Thus one could expect, under most traffic conditions, to see no more than two impulses per second exceeding a threshold level of about 0 dBm/MHZ. Under quiet conditions the rate of occurrence will be much lower.

CONCLUSIONS

The results presented above indicate that pulse arrival rate bears an exponential relationship to peak pulse power. This conclusion is tentative due to the variability in pulse arrival rates caused by traffic density variations. Confidence in measurements would be considerably enhanced if received pulse rates at various power thresholds were measured simultaneously. In addition, a larger number of thresholds at smaller power threshold intervals would provide more points per curve, allowing a better definition of the measured relationship.

An additional conclusion is that an impulse arrival rate of about 2 pps can be expected for a threshold of 0 dBm/MHZ. The arrival rates for lower thresholds will vary widely depending on traffic conditions with a lower value of 2 pps at -20 dBm/MHZ threshold for very quiet traffic conditions and an upper value of about 60 pps at -20 dBm/MHZ for heavy traffic.

Because the pulse arrival rate distributions appear to be considerably skewed toward lower values we can expect the most probable pulse arrival rate to be somewhat lower than the arithmetic average. Thus, the average value can be considered a pessimistic estimate for error-rate calculations.

The question arises as to how can this data be used. As an example of its use, consider the following situation:

(1) Packet burst data rate of 100 kBPS
(2) Packet length of 1000 bits (=10 millisecond packet length)
(3) Receiver bandwidth of 100 KHZ
(4) Receive frequency of 410 MHZ
(5) Receive signal strength of -65 dBm
(6) Receiver antenna omnidirectional with gain of 0 dBi
(7) Receiver located 100 feet from a freeway, so that path loss is 55 dB
(8) Bit errors occur with 100% probability whenever impulse noise power equals or exceeds desired signal power

In the worse case situation, packets are being received end-to-end with no intervening bit spaces. Therefore, 100 packets per second are being received. For the 100 KHZ bandwidth and 55 dB path loss, there is a total reduction of source impulse power of 65 dB. Thus, a source impulse noise power of 0 dBm/MHZ will produce impulse power at the receiver of -65 dBm, just equalling the signal power. From our knowledge of the noise statistics, we can expect, on the average, about 2 impulses per second exceeding this level. Assuming a full packet is lost for one or more bit errors within a packet and no two noise impulses occur less than 10 milliseconds apart, we can expect a loss of two packets for every 100 packets or a throughput of 98%.

Now let us reduce the signal power by 20 dB. At the resulting lower threshold level, we can expect possibly 50 impulses per second, resulting in a loss of 50 packets out of 100 or 50% throughput. This assumes the noise impulse arrival times are evenly distributed.

The above assumptions are overly pessimistic. Packet arrival densities will most likely be much less than 100 packets per second. Impulse arrival rates tend to be exponentially distributed so that the most probable impulse occurrance rates are lower than indicated by the average rate. Also, impulse arrival times will most likely not be evenly distributed within a given time interval so that fewer packets will experience interference.

An additional note may be made in that the use of an error-correcting code and error-correction capability in the receiver should reduce the number of lost packets considerably. This can be realized when one considers that on average there will probably be no more than 50 or 60 erroneous bits per 100,000 bits at 100 KBPS, due to impulse noise interference as described above.

PACKET RADIO IMPLICATIONS

The implications of the above notes in relationship to use of mobile units in the Packet Radio System seem evident. If a hand-held terminal with an omnidirectional antenna (such as a whip antenna) is being used near a street which has a significant amount of automotive traffic, considerable reduction in throughput to the terminal may be encountered due to impulse interference. This will particularly be the case in an urban environment where reception of line-of-sight signals is highly improbable, resulting in low received signal strength. The situation will be even worse for a mobile unit mounted in a vehicle. However, reception at a repeater or station site need not be affected by ignition noise, since antennas at these sites can probably be isolated by distance and shielding from the noise sources.

APPENDIX

```
 STAT1.PLI
BEGIN:
PROC OPTIONS(MAIN);
DCL DAVE FILE;
DCL SYSIN FILE EXT;
DCL (X,S,S2,FN,M,V,D,P,E,C,SEC) FLOAT BIN(31);
DCL N FIXED BIN;
DCL A CHAR(80) VAR;
ON ENDFILE(DAVE) GOTO STOP;
 ON ERROR PUT DATA;
  OPEN FILE(DAVE);
PUT EDIT ('ENTER SECONDS PER SAMPLE') (A);
GET FILE(SYSIN) EDIT (SEC) (F(3));
DO WHILE(1=1);
 N=0; S=0; S2=0;
ENTER:
 GET FILE(DAVE) LIST(X);
 IF X=0 THEN GOTO OUT;
 N=N+1; X=(X-1E0)/SEC;
 S=S+X; S2=S2+X*X;
 GOTO ENTER;
OUT:
 IF N=0 THEN GOTO STOP;
 FN=N;
 M=S/FN;
 V=ABS(S2/FN-M*M);
 D=SQRT(V);
 P=0.6745E0 * D;
 E=SQRT(V/FN);
 C=D/M;
 PUT DATA (N,S,S2,M,V,D,P,E,C);
 PUT SKIP(3);
END;
STOP:
 CLOSE FILE(DAVE);
END;
READY
>

>L SORT1.PLI
**  WAIT
 SORT1.PLI
BEGIN:
PROC OPTIONS(MAIN);
DCL DAVE FILE;
 DCL SYSIN FILE EXT;
DCL (I,K,N,N1,LGE,X,SEC,CNT(50),UNIT(2[illegible])) FIXED BIN;
DCL (FCNT,FN) FLOAT;
[illegible]
DCL A CHAR(80) [illegible];
[illegible] (DAVE) GOTO [illegible];
[illegible]
[illegible]
```

```
00[illegible]   PUT EDIT ('ENTER SECONDS PER SAMPLE') (A);
00[illegible]   GET FILE(SYSIN) EDIT (SEC) (F(3));
00[illegible]   [illegible](1=1);
00[illegible]     [illegible];
00110     [illegible] I=1 TO 50;
00[illegible]      CNT(I)=0;
00130     END;
00140   ENTER:
00150     GET FILE(DAVE) LIST(X);
00160     IF X=0 THEN GOTO OUT;
00170     N=N+1; X=(X-1)/SEC;
00180     DO I=1 BY 10 TO 191;
00190      IF (I-1<=X)&(X<I+9) THEN GOTO L1;
00200     END;
00210     DO I=200 BY 100 TO 900;
00220      IF (I<=X)&(X<I+100) THEN GOTO L2;
00230     END;
00240     PUT (X);
00250     GOTO ENTER;
00260   L1: K=1+(I-1)/10;
00270       GOTO L3;
00280   L2: K=21+(I-200)/100;
00290   L3: CNT(K)=CNT(K)+1;
00300   L4: GOTO ENTER;
00310   OUT:
00315     IF N=0 THEN GOTO STOP;
00320     UNIT(1)=1;
00330     DO I=2 TO 20;
00340      UNIT(I)=(I-1)*10;
00350     END;
00360     DO I=21 TO 28;
00370      UNIT(I)=100+(I-20)*100;
00380     END;
00390     LGE=CNT(1);
00400       DO I=2 TO 28;
00410        LGE=MAX(CNT(I),LGE);
00420      END;
00430     PUT EDIT ('UNIT','FREQ') (SKIP(3),A,X(1),A);
00440     PUT SKIP;
00450     DO I=1 TO 28;
00460      N1=CNT(I)/LGE*50;
00465      FN=N; FCNT=CNT(I); FCNT=FCNT/FN;
00470      PUT EDIT (UNIT(I),FCNT) (SKIP,F(3),X(2),F(5,3))
00480               ((C DO J=1 TO N1)) (X(2),(N1)A);
00490     END;
00500   END;
00510   STOP:
00520     CLOSE FILE(DAVE);
00530   END;
READY
>
```

```
 SORT2.PLI
00010   BEGIN:
00020   PROC OPTIONS(MAIN);
00030   DCL DAVE FILE;
00040    DCL SYSIN FILE EXT;
00050   DCL (I,K,N,N1,LGE,X,SEC,CNT(50),UNIT(28)) FIXED BIN;
00060   DCL (FCNT,FN,CUM) FLOAT;
00070   DCL C CHARACTER(1) INITIAL('X');
00080   DCL A CHAR(80) VAR;
00090   ON ENDFILE(DAVE) GOTO STOP;
00100    ON ERROR PUT DATA;
00110     OPEN FILE(DAVE);
00120   PUT EDIT ('ENTER SECONDS PER SAMPLE') (A);
00130   GET FILE(SYSIN) EDIT (SEC) (F(3));
00140   DO WHILE(1=1);
00150     N=0; K=0;
00160     DO I=1 TO 50;
00170      CNT(I)=0;
00180     END;
00190   ENTER:
00200     GET FILE(DAVE) LIST(X);
00210     IF X=0 THEN GOTO OUT;
00220     N=N+1; X=(X-1)/SEC;
00230     DO I=1 BY 10 TO 191;
00240      IF (I-1<=X)&(X<I+9) THEN GOTO L1;
00250     END;
00260     DO I=200 BY 100 TO 900;
00270      IF (I<=X)&(X<I+100) THEN GOTO L2;
00280     END;
00290     PUT (X);
00300     GOTO ENTER;
00310   L1: K=1+(I-1)/10;
00320       GOTO L3;
00330   L2: K=21+(I-200)/100;
00340   L3: CNT(K)=CNT(K)+1;
00350   L4: GOTO ENTER;
00360   OUT:
00370     IF N=0 THEN GOTO STOP;
00380     UNIT(1)=1;
00390     DO I=2 TO 20;
00400      UNIT(I)=(I-1)*10;
00410     END;
00420     DO I=21 TO 28;
00430      UNIT(I)=100+(I-20)*100;
00440     END;
00450     PUT EDIT ('UNIT','FREQ','CUM') (SKIP(3),A,X(1),A,X(3),A);
00460     PUT SKIP; CUM=0; FN=N;
00470     DO I=1 TO 28;
00480      FCNT=CNT(I); FCNT=FCNT/FN; CUM=CUM+FCNT;
00490      PUT EDIT (UNIT(I),FCNT,CUM)
00500               (SKIP,F(3),X(2),F(5,3),X(2),F(5,3));
00510      IF CUM>0.99 THEN I=28;
00520     END;
00530   END;
00540   STOP:
00550     CLOSE FILE(DAVE);
00560   END;
READY
>
```

PLOT.PLI

```
00010   BEGIN;
00020   PROC OPTIONS(MAIN);
00030   DCL DAVE FILE;
00040   DCL SYSIN FILE EXT;
00050   DCL (X(3000),SEC,X1,N,LGE,N1,N2,N3,SCALE(6),SUM,I,J,
00060        N4,K,INT) FIXED BIN(31);
00070   DCL B CHAR(1) INITIAL(' ');
00080   DCL C CHAR(1);
00090   DCL A CHAR(80) VAR;
00100   ON ENDFILE(DAVE) GOTO STOP;
00110    ON ERROR PUT DATA;
00120     OPEN FILE(DAVE);
00130   PUT EDIT ('ENTER SECONDS PER SAMPLE') (A);
00140   GET FILE(SYSIN) EDIT (SEC) (F(3));
00150   PUT EDIT ('ENTER MAX PLOT LEVEL IN PPS') (A);
00160   GET FILE(SYSIN) EDIT (LGE) (F(4));
00170   PUT EDIT ('ENTER FIRST DATA POINT NUMBER') (A);
00180   GET FILE(SYSIN) EDIT (N3) (F(4));
00190   PUT EDIT ('ENTER NUMBER OF DATA POINTS DESIRED') (A);
00200   GET FILE(SYSIN) EDIT (N2) (F(4));
00210   PUT EDIT ('ENTER NUMBER OF SAMPLES PER DATA POINT')(A);
00220   GET FILE(SYSIN) EDIT (INT) (F(4));
00230   SEC=SEC*INT;
00240   DO WHILE(1=1);
00250   N=1; K=0;
00260   DO I=1 TO 3000;
00270   X(I)=0;
00280   END;
00290   ENTER:
00300    GET FILE(DAVE) LIST(X1);
00310    IF X1=0 THEN GOTO OUT;
00320    X(N)=X(N)+X1-1;
00330    K=K+1;
00340    IF K<INT THEN GOTO ENTER;
00350    X(N)=X(N)/SEC;
00360    N=N+1; K=0;
00370    GOTO ENTER;
00380   OUT:
00390    IF N=1 & K=0 THEN GOTO STOP;
00400    N4=N2+N3;
00410    IF N4>N THEN N4=N;
00420    N2=N4-N3; N=N-1;
00430    PUT EDIT ('SECONDS PER POINT =',SEC)(SKIP,A,X(8),F(4));
00440    PUT EDIT ('TOTAL NUMBER OF POINTS =',N)(SKIP,A,X(3),F(4));
00450    PUT EDIT ('NUMBER OF POINTS PRINTED =',N2)(SKIP,A,X(1),F(4));
00460    SUM=0; SCALE(1)=0;
00470    DO I=2 TO 6;
00480    SUM=SUM + LGE/5;
         SCALE(I)=SUM;
         END;
```

```
00510     PUT EDIT ((SCALE(J) DO J=1 TO 6))(SKIP(3),6F(10));
00520     PUT EDIT (('          .' DO J=1 TO 6))(SKIP,6A(10));
00530     PUT SKIP(2);
00540    PLOT:
00550     DO I=N3 TO N4-1;
00560     N1=(X(I)*50/LGE)+1;
00570     IF N1>51 THEN GOTO L1;
00580     C='X';
00590     GOTO L2;
00600    L1: N1=51;
00610        C='*';
00620    L2: PUT EDIT (X(I),(B DO J=1 TO N1),C)
00630                  (SKIP,F(4),X(4),(N1)A,A);
00640     END PLOT;
00650    PUT SKIP(3);
00660    END;
00670    STOP:
00680     CLOSE FILE(DAVE);
00690    END;
READY
•
```

Table 1.1 PULSE INTERFERENCE DATA FILES

File Name	Record Number	Location	Date	Time Period	Sample Period (sec)	Threshold (μV)
P00A	1	Dole & EW Rd.	2/16/73	9:10-9:30AM	1	100
	2	↑	2/16/73	9:30-9:50AM	1	200
	3	↕	2/16/73	9:50-10:10AM	1	400
P01A	1	↕	2/22/73	8:25AM-5:32PM	100	200
	2	↕	2/23/73	7:18AM-6:46PM	100	400
	3	↕	2/28/73	8:04AM-5:00PM	100	800
P02A	1	↕	3/15/73	8:18AM-5:01PM	50	100
	2	↓	3/16/73	8:55AM-5:36PM	50	100
P03A	1	Dole & EW Rd.	3/14/73	4:00-5:00PM	1	100
P04A	1	Freeway	3/27-3/28/73	1:55PM-1:50PM	50	100
	2	↑	3/28-3/29/73	1:55PM-1:50PM	50	200
	3	↕	3/29-3/30/73	1:55PM-2:10PM	50	400
	4	↕	3/30-3/31/73	2:16PM-2:21PM	50	800
P05A	1	↕	3/31/73	2:40-2:55PM	1	100
	2	↕	3/31/73	2:56-3:11PM	1	200
	3	↕	3/31/73	3:15-3:30PM	1	400
	4	↕	3/31/73	3:32-3:47PM	1	800
P06A	1	↕	4/2/73	4:47-5:02PM	1	100
	2	↕	4/2/73	5:04-5:19PM	1	200
	3	Freeway	4/2/73	5:22-5:37PM	1	400

Table 1.2 SOURCE THRESHOLD LEVEL CALIBRATION

Receiver Threshold (Microvolts)	Source Threshold (dBm/MHZ)
100	-19.7
200	-13.7
400	- 7.7
800	- 1.7

NOTES: (1) Values apply to both locations.

(2) Based on measured path loss of 46 dB.

(3) Based on receiver threshold level at 100 μVolts, calculated as follows:

Threshold Level (100 μV):	-67.0 dBm
Bandwidth Factor (1.35):	+ 1.3 dB
Threshold Level (dBm/MHZ):	-65.7

Table 1.3 PULSE INTERFERENCE DATA STATISTICS

File Name	Record Number	Number of Samples	Mean Pulse Rate (PPS)	Standard Deviation (PPS)	Standard Error of the Mean (PPS)	Coefficient of Variation
P00A	1	910	52.9	45.0	1.49	0.85
	2	957	23.8	49.7	1.61	2.09
	3	1058	10.4	33.4	1.03	3.20
P01A	1	327	24.1	12.5	0.69	0.52
	2	412	10.0	8.8	0.43	0.88
	3	321	2.2	4.9	0.28	2.29
P02A	1	624	35.9	15.5	0.62	0.43
	2	618	48.8	17.0	0.68	0.35
P03A	1	2884	65.5	42.1	0.78	0.64
P04A	1	1713	28.8	18.4	0.44	0.64
	2	1713	13.3	11.7	0.28	0.88
	3	1737	6.6	7.3	0.17	1.10
	4	1732	1.5	2.6	0.06	1.74
P05A	1	701	36.0	50.2	1.89	1.40
	2	735	23.9	50.1	1.85	2.09
	3	726	6.2	21.5	0.80	3.44
	4	710	2.0	19.0	0.71	9.37
P06A	1	718	32.9	60.8	2.27	1.85
	2	721	14.9	42.4	1.58	2.84
	3	722	7.1	27.0	1.01	3.83

Table 1.4 PULSE INTERFERENCE DATA RESULTS

File Name	Rec. No.	N	PULSE RATE (PPS) Mean	Standard Deviation	Coefficient of Var.	Sample Period (sec)	Threshold (μV)	Date	Time	Location
P00A	1	910	52.9	45.0	0.85	1	100	2/16/73	9:10-9:30AM	Dole & EW Rd.
	2	957	23.8	49.7	2.09	1	200	2/16/73	9:30-9:50AM	
	3	1058	10.4	33.4	3.20	1	400	2/16/73	9:50-10:10AM	
P01A	1	327	24.1	12.5	0.52	100	200	2/22/73	8:25AM-5:32PM	
	2	412	10.0	8.8	0.88	100	400	2/23/73	7:18AM-6:46PM	
	3	321	2.2	4.9	2.29	100	800	2/28/73	8:04AM-5:00PM	
P02A	1	624	35.9	15.5	0.43	50	100	3/15/73	8:18AM-5:01PM	
	2	618	48.8	17.0	0.35	50	100	3/16/73	8:55AM-5:36PM	
P03A	1	2884	65.5	42.1	0.64	1	100	3/14/73	4:00-5:00PM	Dole & EW Rd.
P04A	1	1713	28.8	18.4	0.64	50	100	3/27-3/28	1:55-1:50PM	Freeway
	2	1713	13.3	11.7	0.88	50	200	3/28-3/29	1:55-1:50PM	
	3	1737	6.6	7.3	1.10	50	400	3/29-3/30	1:55-2:10PM	
	4	1732	1.5	2.6	1.74	50	800	3/30-3/31	2:16-2:21PM	
P05A	1	701	36.0	50.2	1.40	1	100	3/31/73	2:40-2:55PM	
	2	735	23.9	50.1	2.09	1	200	3/31/73	2:56-3:11PM	
	3	726	6.2	21.6	3.44	1	400	3/31/73	3:15-3:30PM	
	4	710	2.0	19.0	9.37	1	800	3/31/73	3:22-3:47PM	
P06A	1	718	32.9	60.8	1.85	1	100	4/2/73	4:47-5:02PM	
	2	721	14.9	42.4	2.84	1	200	4/2/73	5:04-5:19PM	
	3	722	7.1	27.0	3.83	1	400	4/2/73	5:22-5:37PM	Freeway

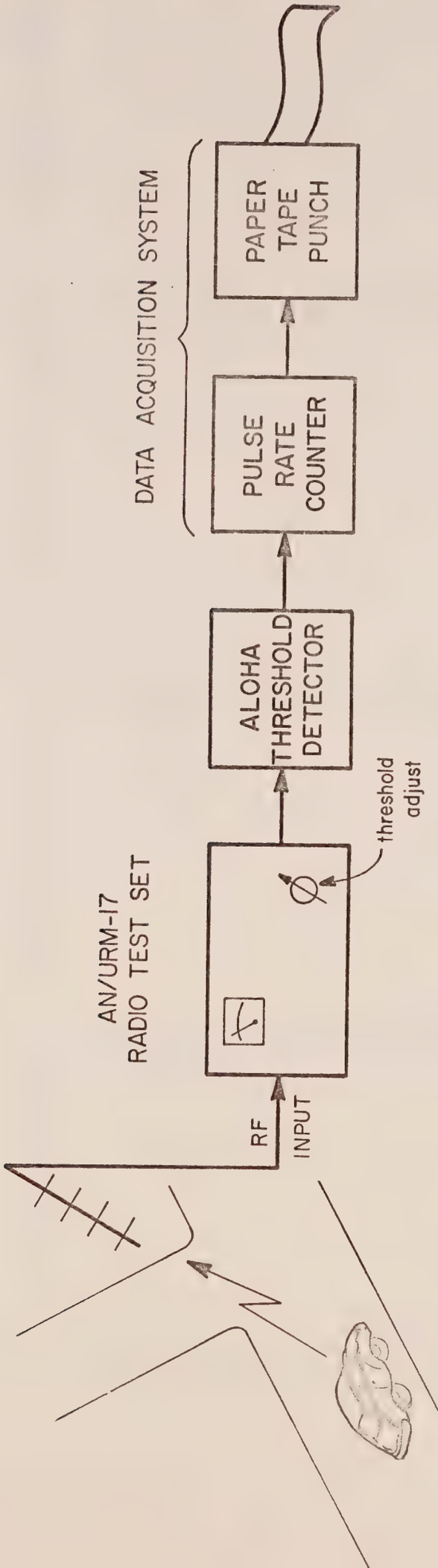


Figure I.I INSTRUMENTATION SET UP

Figure 1.2 TRUNCATION OF PULSE ARRIVAL RATE DISTRIBUTION WITH SHIFT OF RECEIVER THRESHOLD

(Data taken from files P01A and P02A)

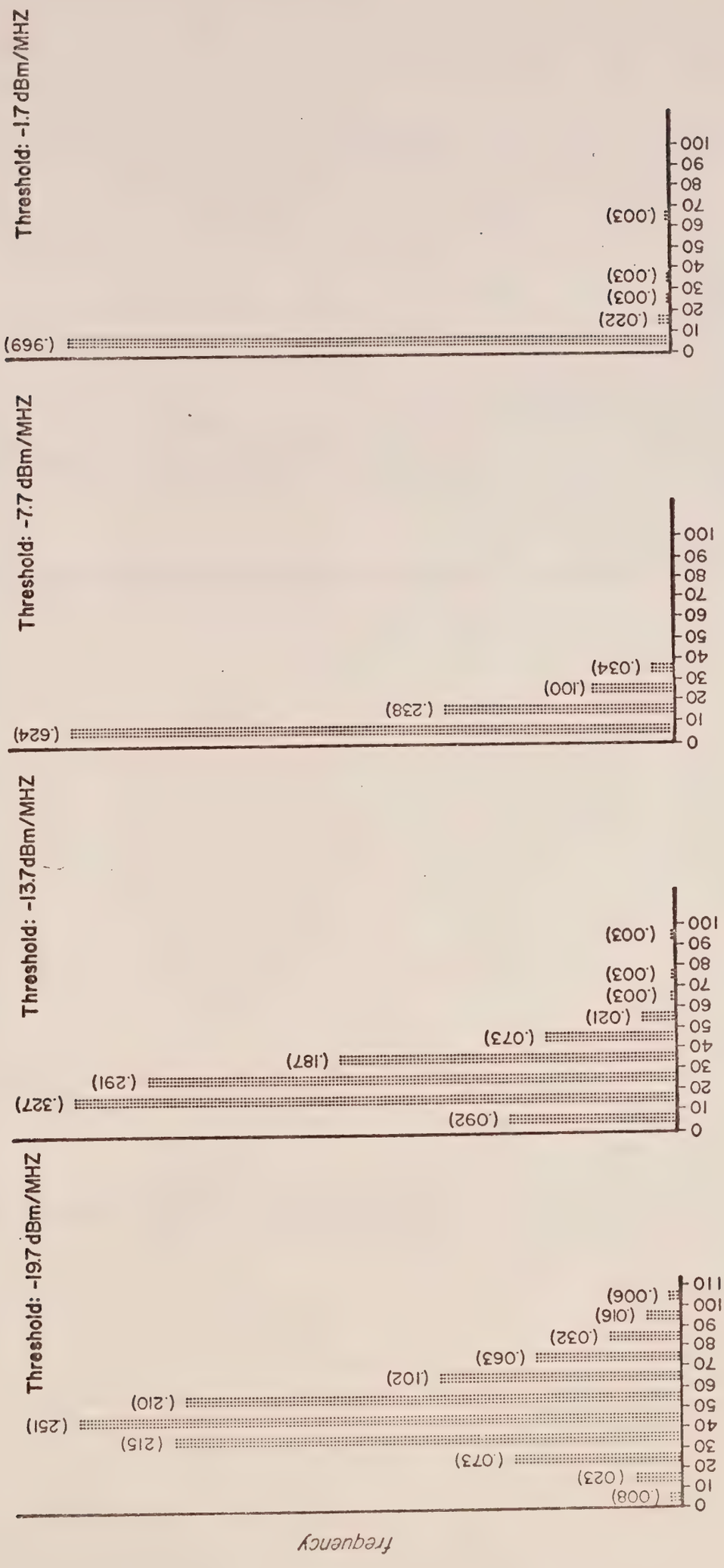


Figure 1.3 DAY-TO-DAY SHIFT OF MEAN PULSE ARRIVAL RATE

(Data taken from file P02A)

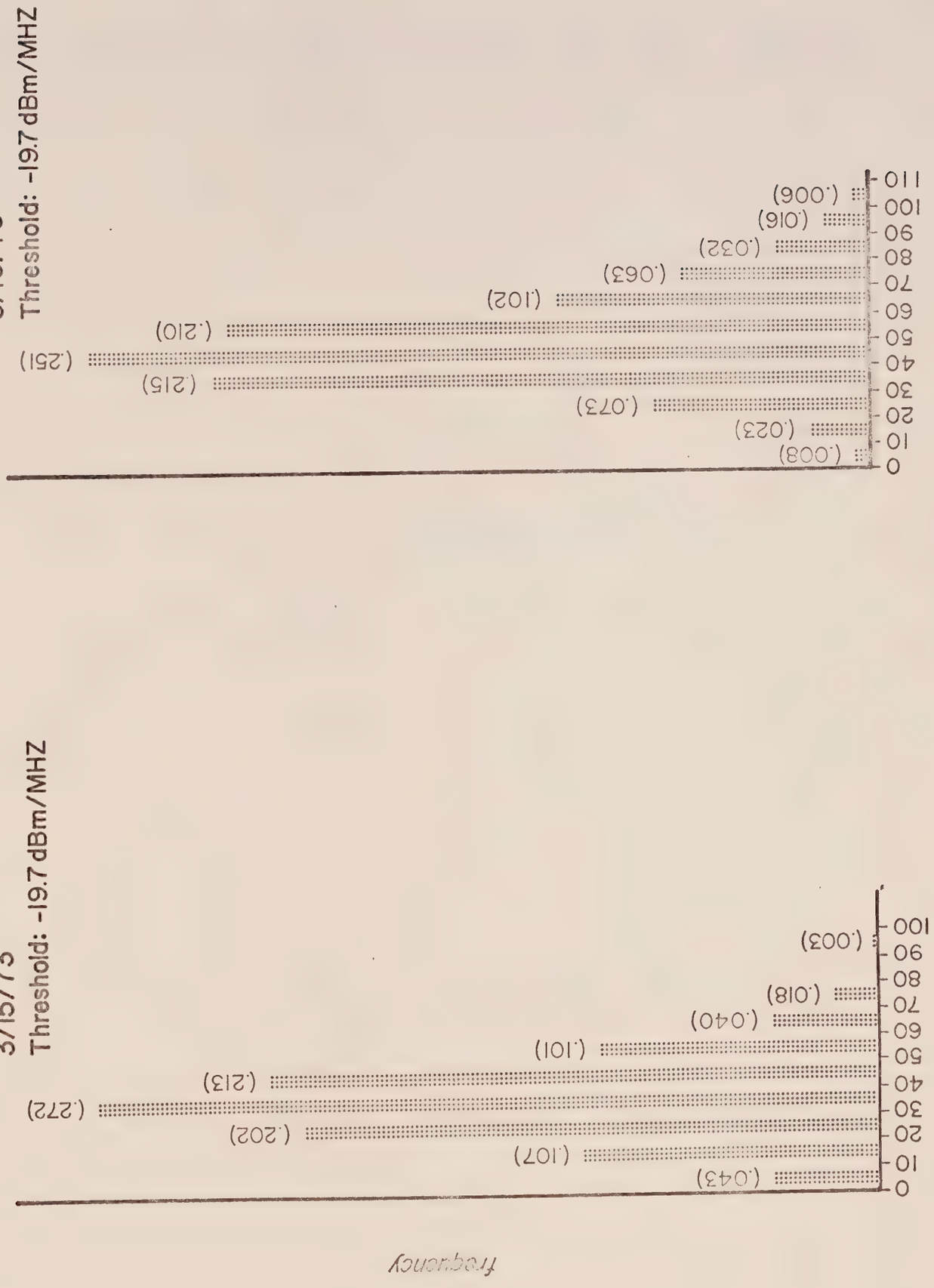
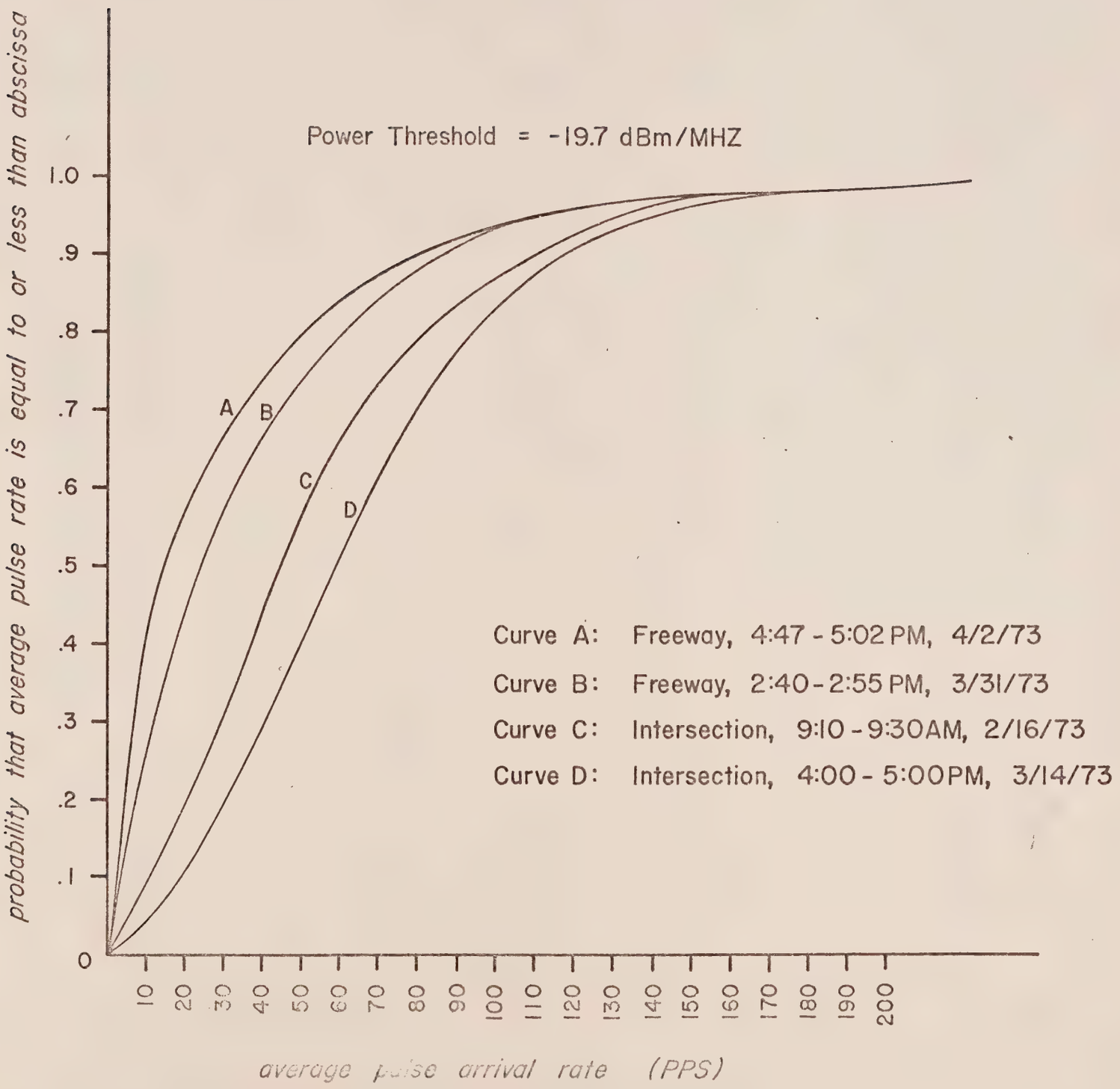


Figure 1.4 CUMULATIVE DISTRIBUTIONS OF ONE SECOND PULSE RATE SAMPLES



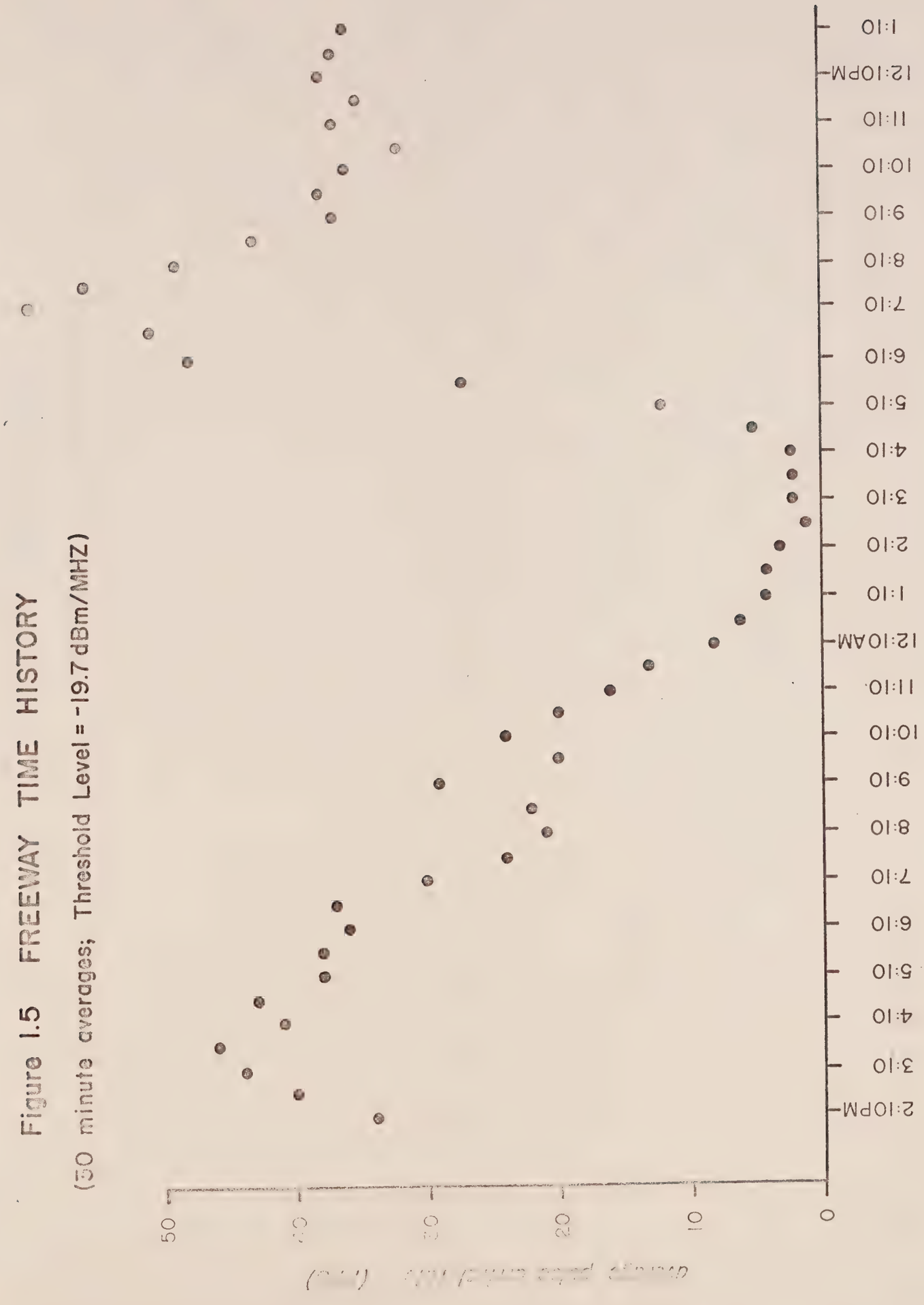


Figure 1.5 FREEWAY TIME HISTORY

(30 minute averages; Threshold Level = -19.7 dBm/MHZ)

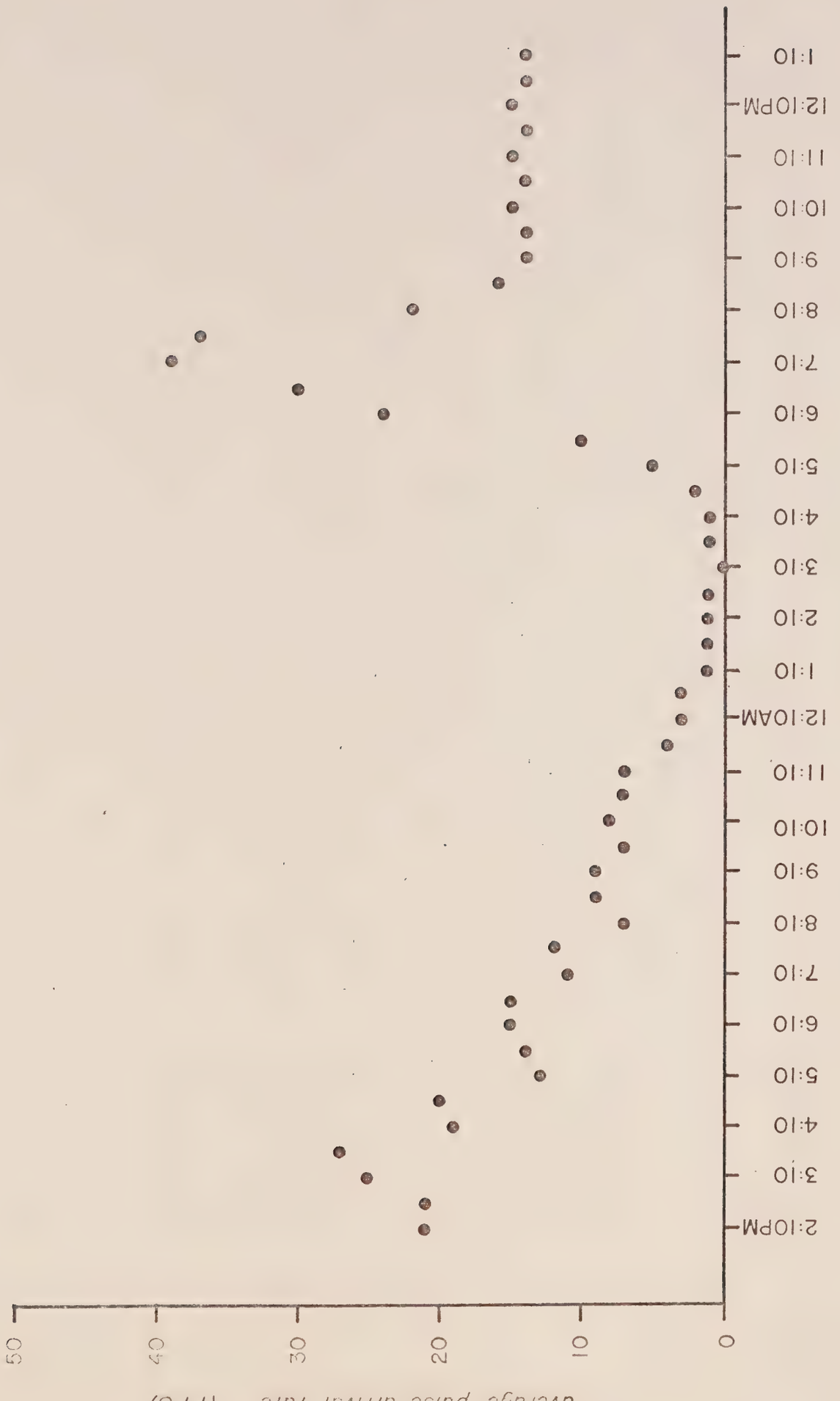


Figure 1.6 FREEWAY TIME HISTORY

(30 minute averages; Threshold Level = -13.7 dBm/MHZ)

Figure 1.7 FREEWAY TIME HISTORY

(30 minute averages; Threshold Level = -7.7 dBm/MHZ)

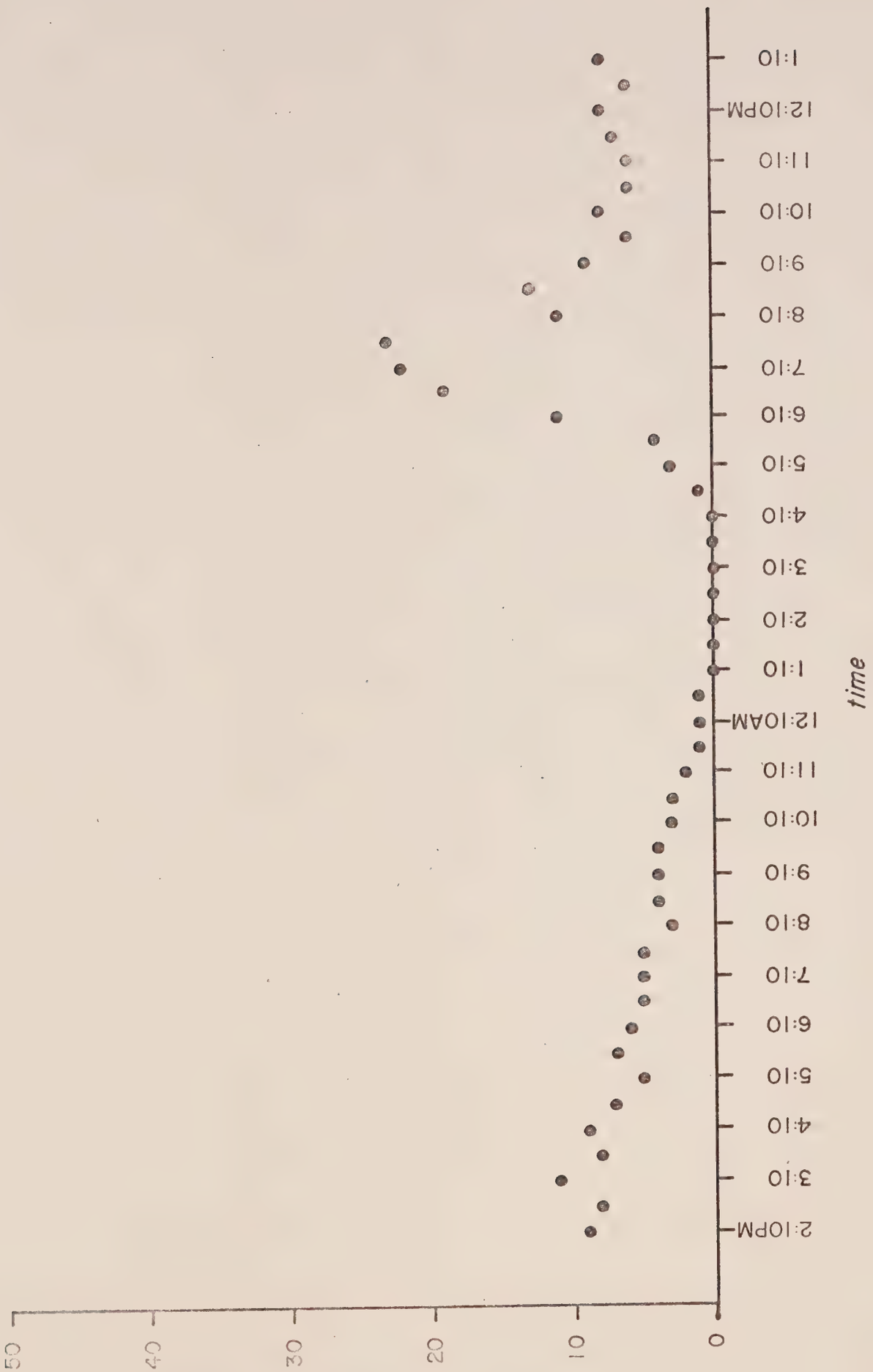


Figure 1.8 FREEWAY TIME HISTORY

(30 minute averages; Threshold Level = -1.7 dBm/MHZ)

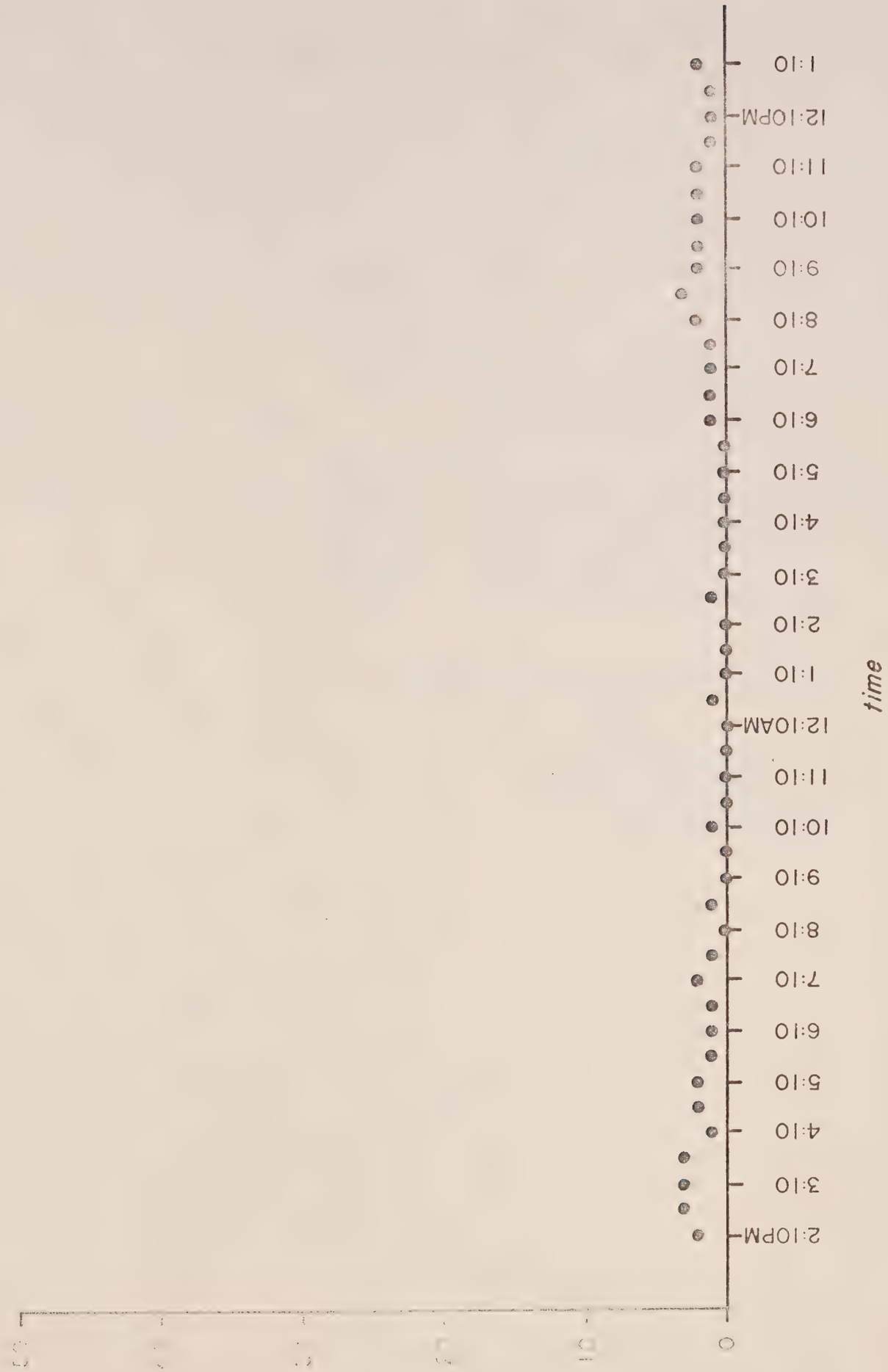
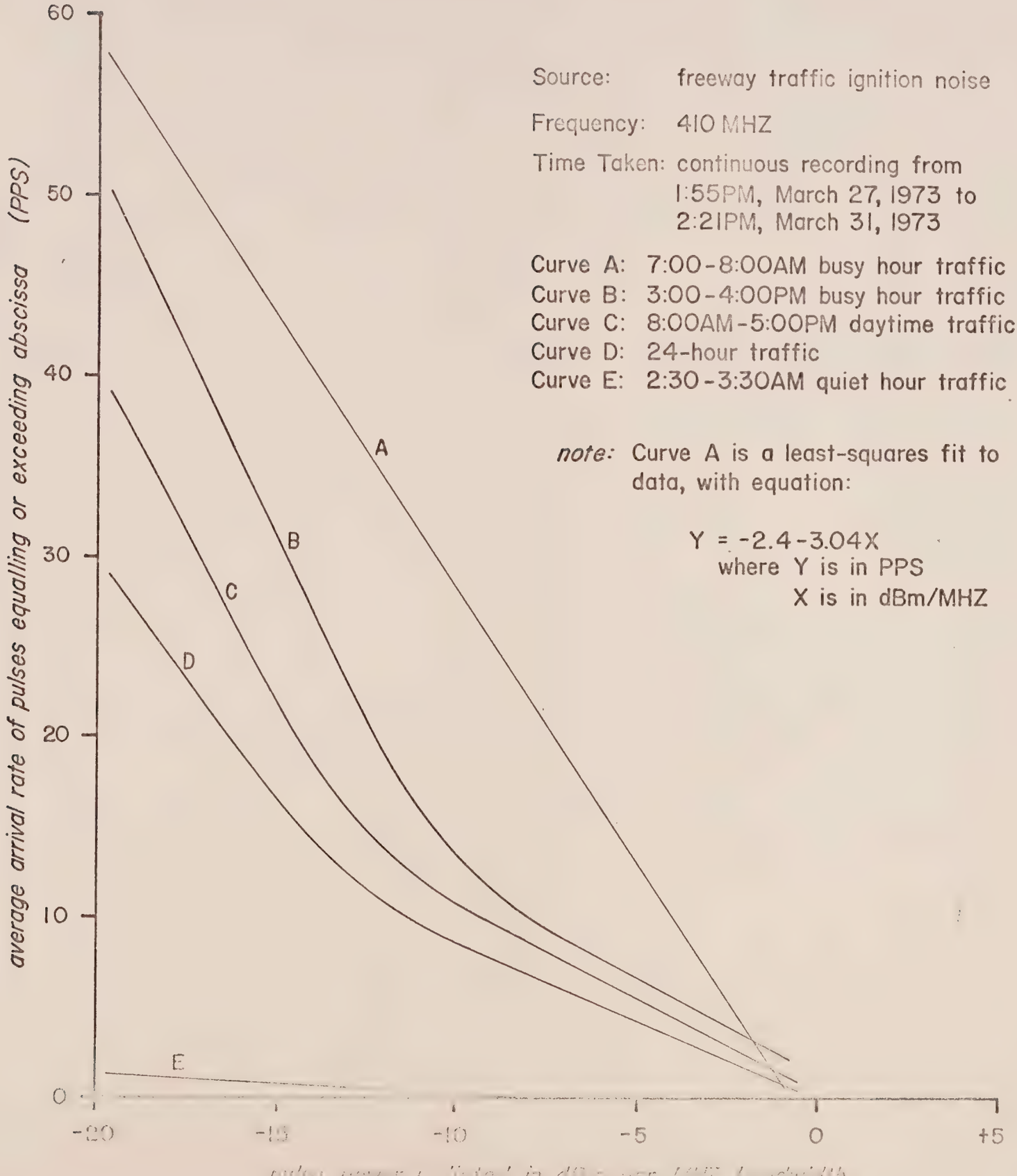


Figure 1.9 CUMULATIVE PULSE ARRIVAL RATE vs. RADIATED POWER LEVEL



Source: freeway traffic ignition noise

Frequency: 410 MHZ

Time Taken: continuous recording from 1:55PM, March 27, 1973 to 2:21PM, March 31, 1973

Curve A: 7:00-8:00AM busy hour traffic
Curve B: 3:00-4:00PM busy hour traffic
Curve C: 8:00AM-5:00PM daytime traffic
Curve D: 24-hour traffic
Curve E: 2:30-3:30AM quiet hour traffic

note: Curve A is a least-squares fit to data, with equation:

$$Y = -2.4 - 3.04X$$

where Y is in PPS
X is in dBm/MHZ

Figure I.10 CUMULATIVE PULSE ARRIVAL RATE vs. RADIATED POWER LEVEL

(comparison of freeway data to street intersection data for 8:00AM to 5:00PM daytime traffic)

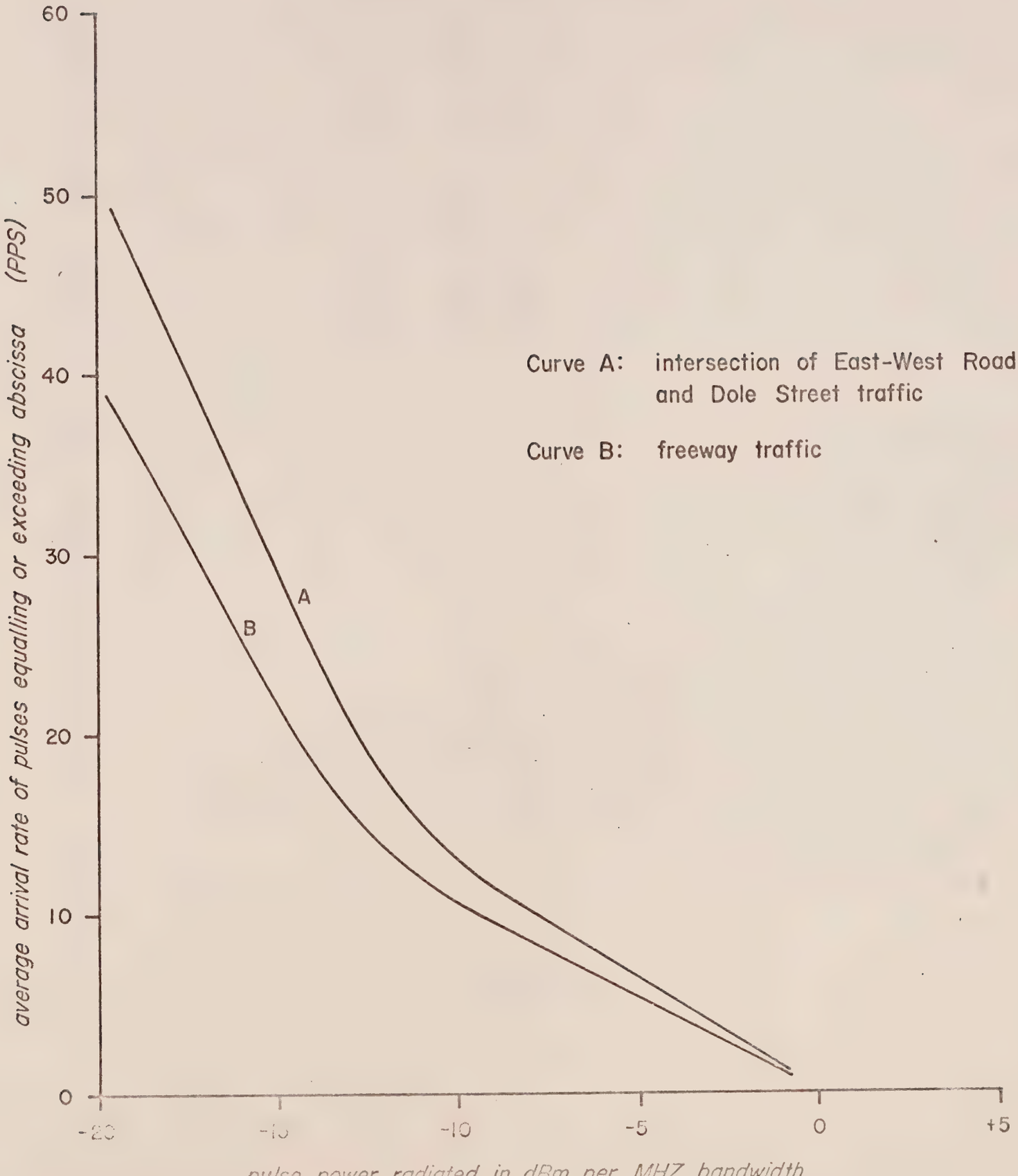
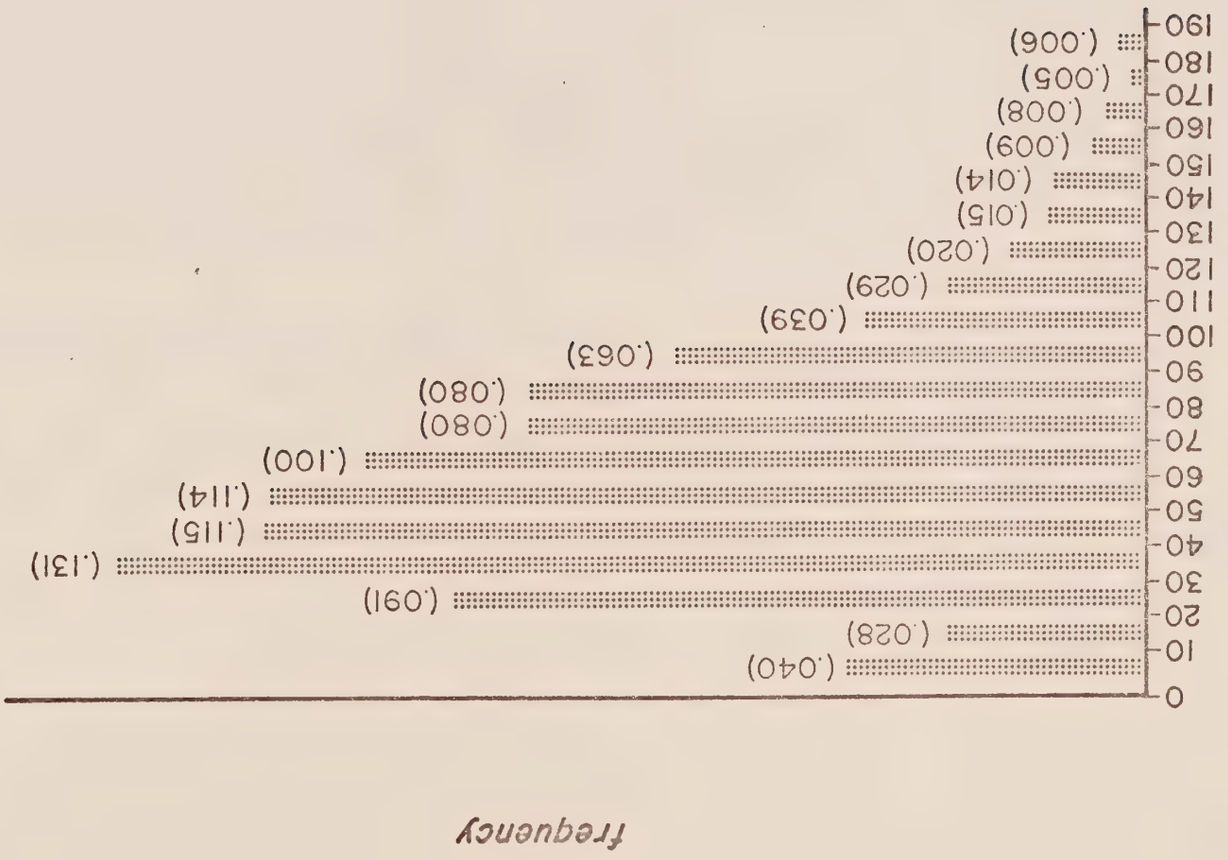


Figure I.11 FREQUENCY DISTRIBUTION OF PULSE ARRIVAL RATE



PART 2 LOSS MEASUREMENT OF FIELD STRENGTH FOR ALOHA CHANNEL

INTRODUCTION

The attenuation of radio field strength over that of free space loss due to irregular terrain and obstacles such as tall buildings, is caused by reflections, diffractions, and absorption of the signal. This additional attenuation is quite significant in urban and suburban areas. The purpose of this note is to report on measurements made by ALOHA in the Honolulu area near the University of Hawaii campus and to compare these measurements to those reported by Y. Okumura, et al., [1] in 1968. Y. Okumura, E. Ohmori, T. Kawano and K. Fukuda (1968) made a complete survey of the field strength in VHF and UHF for land-mobile radio service in Japan.

In order to investigate and collect data for the loss measurement of field strength in the ALOHA UHF channel, the measurement program under THE ALOHA SYSTEM Project has been made at 413 MHz over various situations of elevation and environments. The collected data were then analyzed statistically.

MEASUREMENT AND SELECTION OF SAMPLE PLACES

Since there was little local data available at UHF for the ALOHA channel, a measurement program was devised to provide radio range statistics for the ALOHA radio channel. Several measurement places in the Kaimuki, Beretania, Manoa and Waikiki districts were selected by drawing concentric circles centered at the ALOHA central transmitter antenna on the University of Hawaii campus, with radii of 0.5, 1.0, 1.5, 2.0 and 2.5 mile increments. All the sample places are shown in Table 2.1.

All measurements were taken at ground level except for a few measurements which were taken on the roof of tall buildings for purposes of comparison to ground-level measurements. All data was taken in the afternoon, between 1:30 and 4:30 PM. In order to minimize reflection and diffraction, it is better to keep away from tall buildings, walls, wire-fences, and automobiles. Antenna pointing angles of the maximum reading were recorded to provide some information about the direction of the maximum received signal. It helps us to understand

whether the transmitted or reflected signals were received. At each location, four separate readings were made, each several wavelengths away from the others, in order to obtain an average value for the sample location.

EQUIPMENT

Signal is generated at 413 MHz and transmitted from the roof of the Hawaii Institute of Geophysics. A calibrated dipole antenna and a Tektronix Type 1401A/324 portable spectrum analyzer were used to measure the received signal level at the chosen places. The analyzer's built-in calibrator with accuracy of 0.5 db was used to ensure that accurate readings were obtained. A portable compass was also used to provide reading of direction (angle).

DATA ANALYSIS AND RESULTS

Table 2.2 shows the data measured in the Manoa Area
Table 2.3 shows the data measured in the Kaimuki Area
Table 2.4 shows the data measured in the Beretania Area
Table 2.5 shows the data measured in the Waikiki Area

These tables enable us to relate location, distance, and elevation to the loss of field strength. Angle also tells us whether the received maximum signal is a transmitted or reflected signal. Some statistical analysis was performed on the data and the results are shown in Table 2.6 through 2.9. The measured loss data shown in the tables are calculated from measured field strength data (in dBm) and the equivalent radiated power of the transmitting station. The measured field strength is the average of four measurements made at each location.

By the technique of linear regression, we find a line of regression for the data. The method is straight forward. Let x represent the logarithm of the distance and Y be defined as the maximum reading. By solving the following simultaneous equations:

$$\sum Y = N \cdot a + b \sum x \quad (1)$$

$$\sum xY = a \sum x + b \sum x^2 \quad (2)$$

We can find a and b. Substituting a, b into Y=a+bx, we get the line of regression.

This line is plotted in Figures 2.1 through 2.4. Note that data measured at Leahi Hospital and Queen's Medical Center are not included in the calculation of Y=a+bx since they do not represent the ground level measurements.

In order to find the standard error of estimate, Sy, (which is the deviation from theoretical value, or Y-Yc=d) is calculated.

It is expressed as $Sy=\sqrt{\Sigma d^2/N}$, where N is the number of the measurements. All the calculations are shown in Appendices 2.1 through 2.4.

Theoretically, the relationship between attenuation, distance, and frequency in free space can be expressed as:

$$A = 36.6 + 20 \log f + 20 \log d$$

where A is the free space attenuation (in db)
f is the frequency of transmitted signal (in MHz)
d is the distance (in miles)

The predicted line for free space attenuation is shown in the figures. Comparing this line to the measured one, i.e., line of regression, it reveals that attenuation in practice is more than the theoretical value. Also, by comparison to the corrected Okumura's result in which all the correction factors have been taken into account, our results have much the same slope, but less attenuation.

One thing interesting in the Waikiki Area is that the measurement on the top of Waikiki Sheraton Hotel (about 290 feet high) is 91 db loss which is the lowest for that range, according to our records. And we found that the difference between the ground level (5 feet) and the top (290 feet) is more than 20 db. Also, the measurements at both sides of the Ala Wai Canal (could be considered as unobstructed) are almost the same. It shows that obstacles or tall buildings play an important role in the loss of field strength.

Figure 2.4 shows that our result (the slope) is the same as Okumura's in the urban area except that we do not have as much attention.

CONCLUSIONS

From the previous results, we see that signal attenuation increases with distance at the same rate as that predicted by Okumura's data, except that our measured loss is considerably less than the predicted loss. Perhaps the characteristics of our suburban and urban areas are different from those encountered in Japan for the Okumura measurements. This result does indicate the importance of performing radio range measurements in areas where packet

radio systems are to be implemented.

The angle measurements show that in most cases a direct line-of-sight signal is received at the antenna. A few measurements showed the strongest signal to be a reflected one. This result supports the previous result of less loss than predicted.

FUTURE PLANS

Measured field strength at Leahi Hospital indicates that adequate signal power will be received at this site for the establishment of a packet radio repeater. Future measurements will be made relative to the Leahi site to provide a second loss model. Equal-power locations, relative to the two transmitting sites, will then be selected for future tests of capture effects in suburban and urban environments.

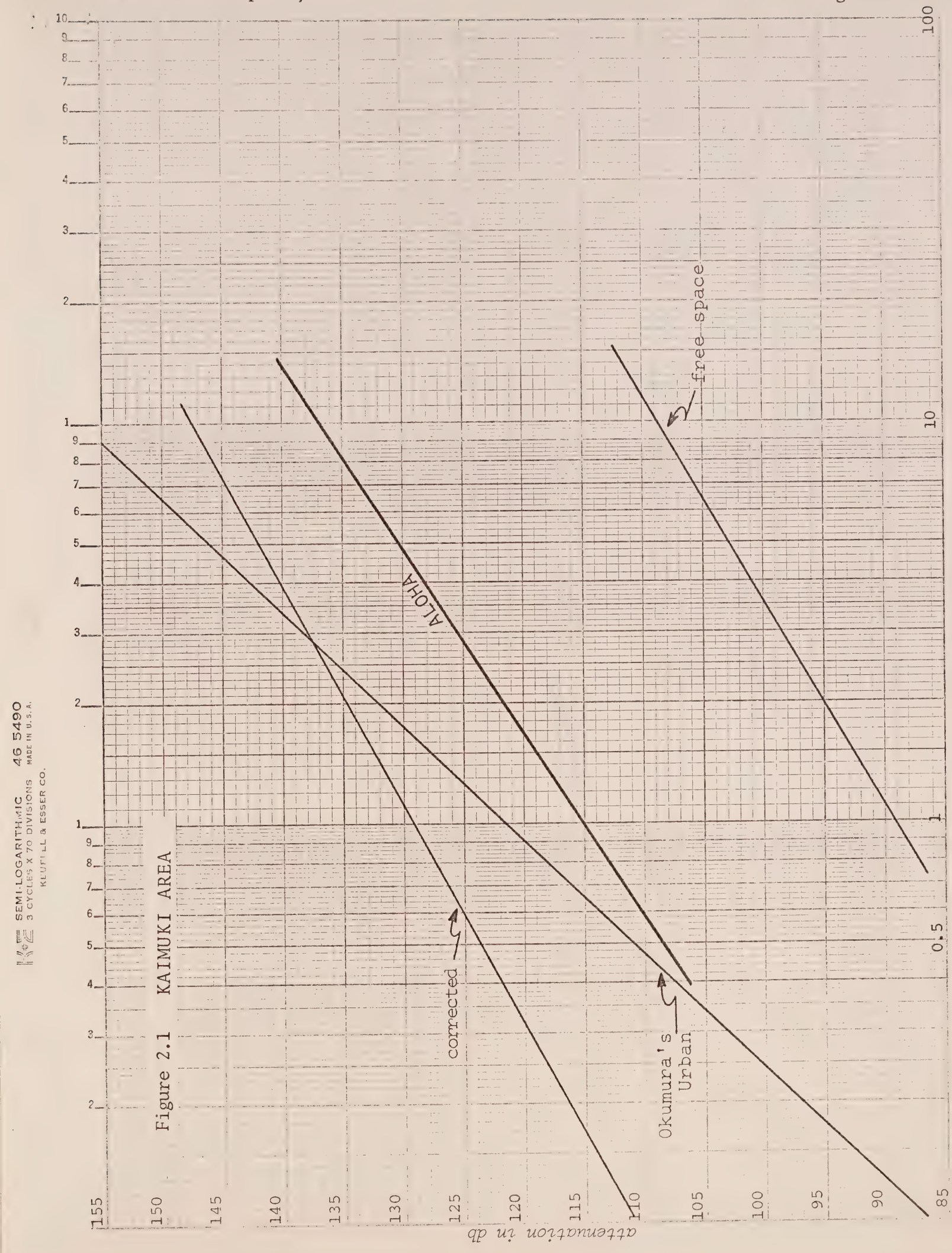
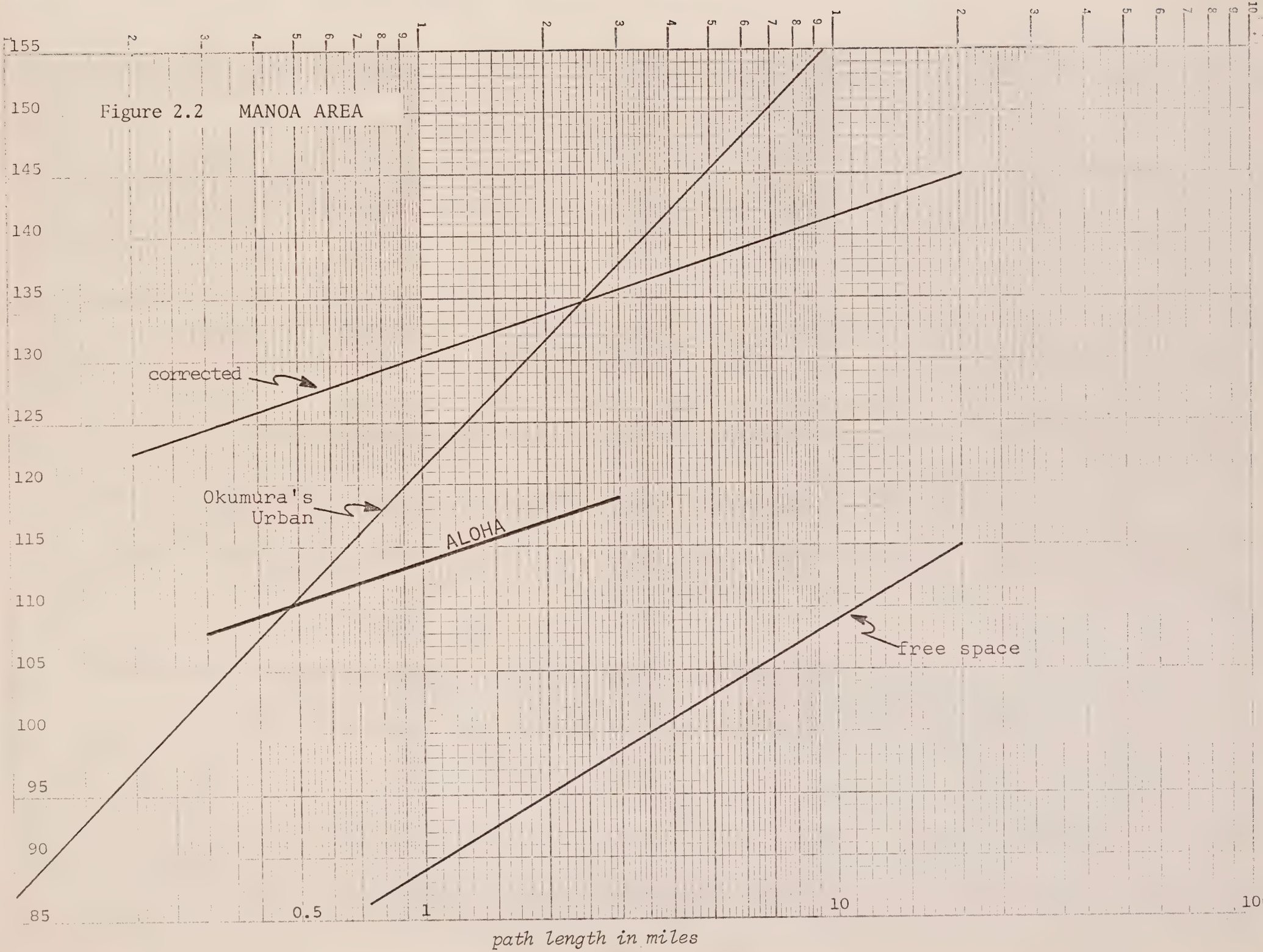


Figure 2.1 KAIMUKI AREA

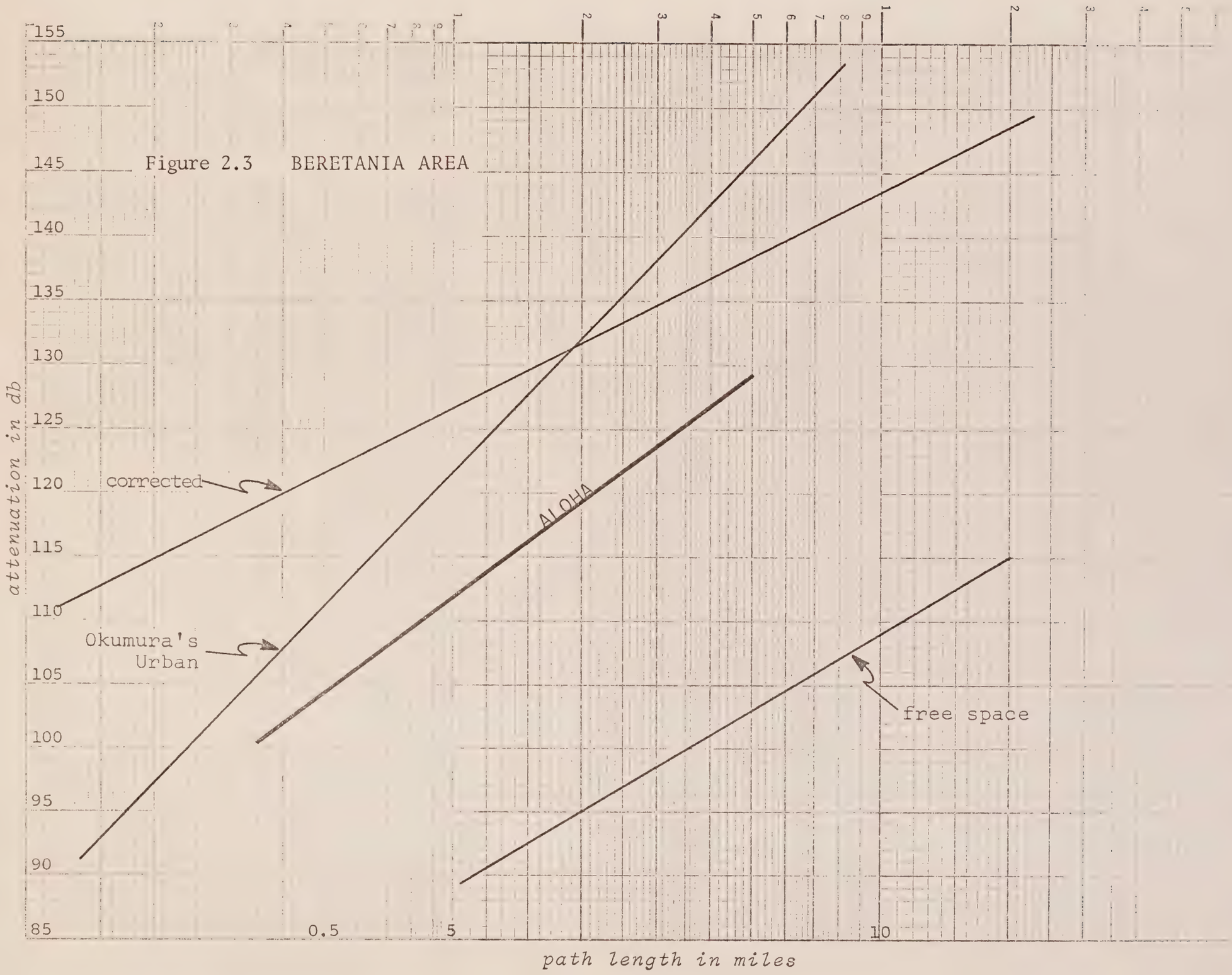
SEMI-LOGARITHMIC 46 5490
3 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

Figure 2.2 MANOA AREA



SEMI-LOGARITHMIC 46 5490
3 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

Figure 2.3 BERETANIA AREA



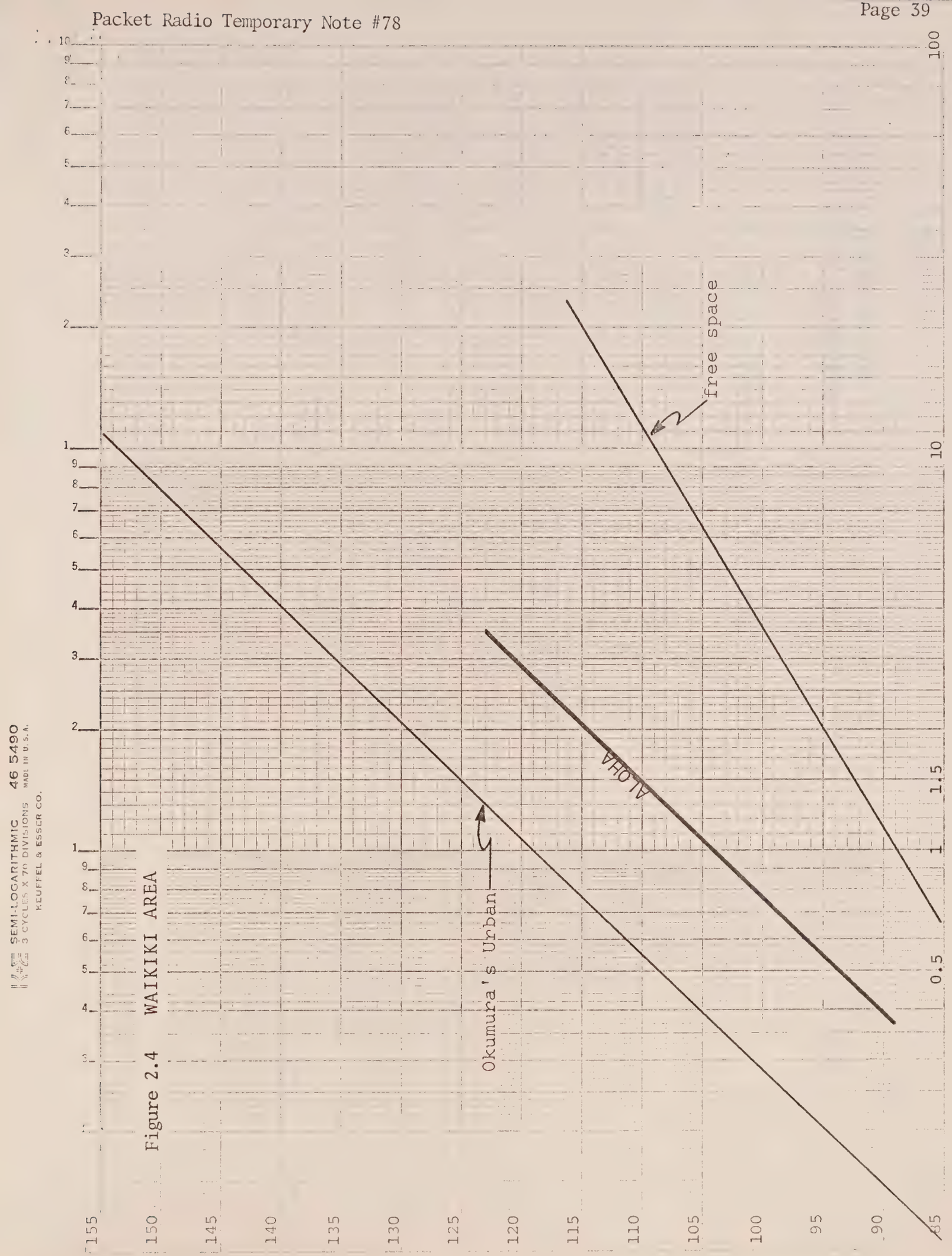


Figure 2.4 WAIKIKI AREA

Table 2.1

SAMPLE PLACES IN THE FIELD STRENGTH MEASUREMENT

	Code	Distance (miles)
BERETANIA AREA		
Dole and Hoonanea	B1	0.5
Beretania and Pawaa	B2	1.0
Young and Keeaumoku	B3	1.5
McKinley High School	B4	2.0
Queen's Hospital	B5	2.5
MANOA AREA		
University and Halelea Pl.	M1	0.5
Oahu and Kaaipu	M2	1.0
Poelua and Halelani Dr.	M3	1.5
Manoa and Nipo	M4	2.0
KAIMUKI AREA		
Dole Street	K1	0.5
Kapahulu and Mokihana	K2	1.0
Kapahulu and Kanaina	K3	1.5
Leahi Hospital	K4A	2.0
Monsarrat and Paki	K4B	
Kalakaua and Paki	K5	2.5
WAIKIKI AREA		
Varsity Theater	W1	0.5
Kapiolani and Isenberg	W2	1.0
Sheraton Waikiki Hotel	W3	1.55
International Market Place	W4	1.65
Ala Wai and Kalaimoku	W5	1.2

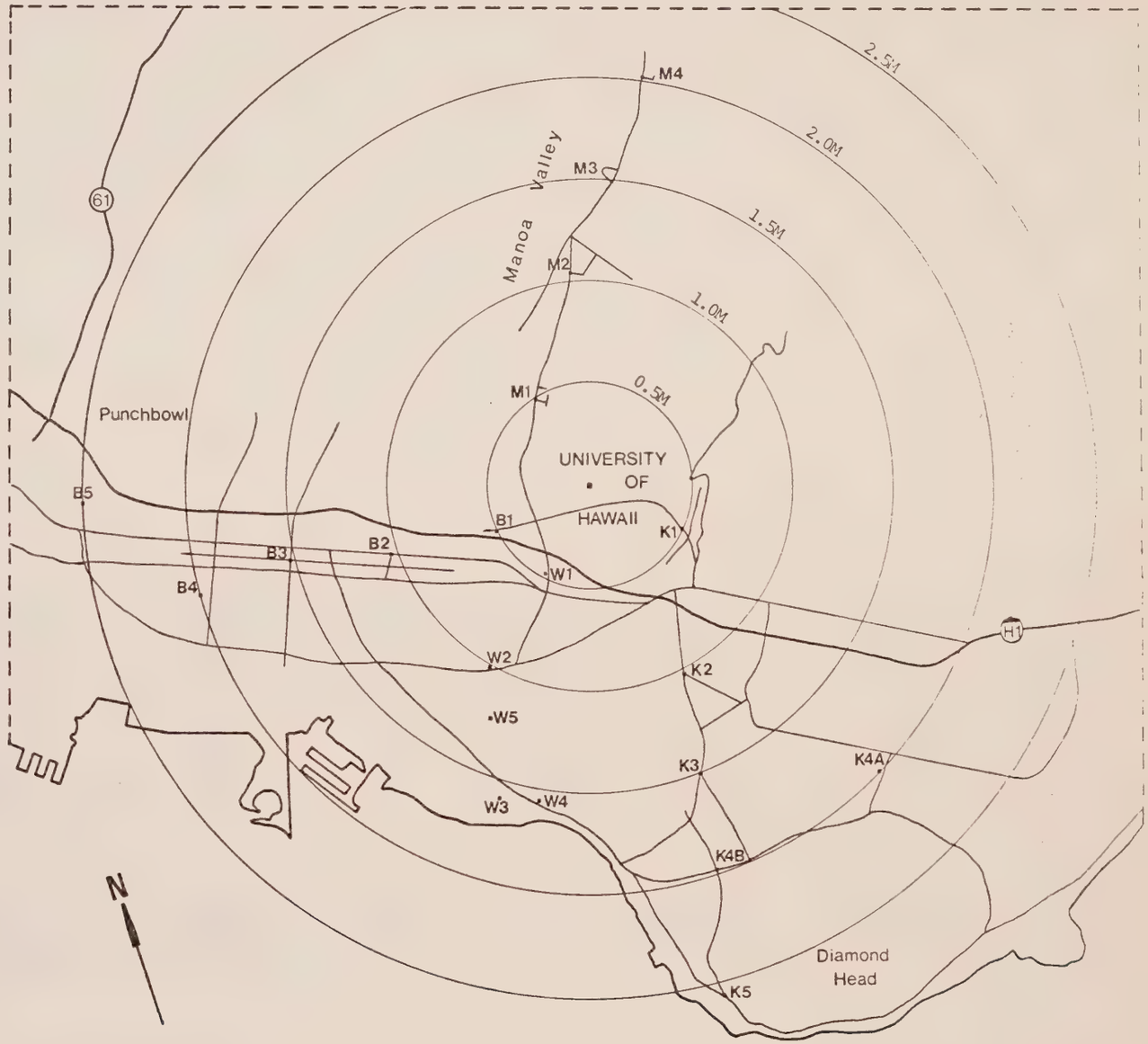


Table 2.2 DATA IN THE MANOA AREA

Location	*Distance (miles)*	*Date*	*Time*	*Elevation (feet)*	*Measured Loss (DB)*	*Angle (Rel. Mag. No.)*	*Calculated Loss (DB)*
M1	0.5	7/7/73	PM	120	109	180°	105.57
M2	1.0	7/8/73	PM	160	116	193°	113.77
M3	1.5	7/8/73	PM	240	118	190°	115.69
M4	2.0	7/8/73	PM	360	114	200°	116.97

Table 2.3 DATA IN THE KAIMUKI AREA

Location	*Distance (miles)*	*Date*	*Time*	*Elevation (feet)*	*Measured Loss (DB)*	*Angle (Rel. Mag. No.)*	*Calculated Loss (DB)*
K1	0.5	7/7/73	PM	100	104	320°	108.46
K2	1.0	7/7/73	PM	21	122	315°	115.05
K3	1.5	7/7/73	PM	9	119	330°	119.01
K4A	2.0	7/5/73	PM	270	106	325°	121.64
K4B	2.0	7/7/73	PM	24	125	312°	121.64
K5	2.5	7/5/73	PM	9	118	0°	123.84

Table 2.4 DATA IN THE BERETANIA AREA

Location	*Distance (miles)*	*Date*	*Time*	*Elevation (feet)*	*Measured Loss (DB)*	*Angle (Rel. Mag. No.)*	*Calculated Loss (DB)*
B1	0.5	7/12/73	PM	9	116	36°	114.21
B2	1.0	7/12/73	PM	20	113		116.85
B3	1.5	7/12/73	PM	30	119	110°	118.43
B4	2.0	7/12/73	PM	10	121	65°	119.49
B5	2.5	7/12/73	PM	150	122	235°	120.37

Table 2.5 DATA IN THE WAIKIKI AREA

Location	*Distance (miles)*	*Date*	*Time*	*Elevation (feet)*	*Measured Loss (DB)*	*Angle (Rel. Mag. No.)*	*Calculated Loss (DB)*
W1	0.5	7/12/73	PM	9	97		93.63
W2	1.0	7/12/73	PM	5	100		104.08
W3(ground)	1.55	7/12/73	PM	5	114		110.70
W3(top)	1.55	7/12/73	PM	293	91		
W4	1.65	7/12/73	PM	5	116		111.74
W5	1.2	7/12/73	PM	5	100		106.87

Table 2.6

SOME STATISTICS OF THE MEASUREMENT IN THE BERETANIA AREA

	P	$x=\log_{10}P$	Y	x^2	xY	Y^2	Yc	Y-Yc=d	d^2
1	0.5	-0.3	116	0.09	-34.8	13456	114.21	1.79	3.20
2	1.0	0	113	0	0	12769	116.85	-3.85	14.82
3	1.5	0.18	119	0.032	21.42	14161	118.43	0.57	0.32
4	2.0	0.3	121	0.09	36.3	14641	119.49	1.51	2.28
SUM		0.18	469	0.212	22.92				20.63

Note: Y: Maximum Reading

Yc: Theoretical Value From Line of Regression

Table 2.7

SOME STATISTICS OF THE MEASUREMENT IN THE MANOA AREA

	P	$x=\log_{10}P$	Y	x^2	xY	Y^2	Yc	Y-Yc=d	d^2
1	0.5	-0.3	109	0.09	-32.7	11881	110.57	-1.57	2.46
2	1.0	0	116	0	0	13456	113.77	2.23	4.97
3	1.5	0.18	118	0.032	21.24	13924	115.69	2.31	5.34
4	2.0	0.3	114	0.09	34.2	12996	116.97	-2.97	8.82
SUM		0.18	457	0.212	22.74				21.59

Table 2.8

SOME STATISTICS OF THE MEASUREMENT IN THE KAIMUKI AREA

	P	$x=\log_{10}P$	Y	x^2	xY	Y^2	Yc	Y-Yc=d	d^2
1	0.5	-0.3	104	0.09	-31.2	10816	108.46	-4.46	19.89
2	1.0	0	122	0	0	14884	115.05	6.95	48.30
3	1.5	0.18	119	0.032	21.42	13689	119.01	0.01	0.0001
4	2.0	0.3	125	0.09	37.5	15376	121.64	3.36	11.29
5	2.5	0.4	118	0.16	47.2	13924	123.84	-5.84	34.16
SUM		0.58	588	0.372	74.9				113.64

Table 2.9

SOME STATISTICS OF THE MEASUREMENT IN THE WAIKIKI AREA

	P	$x=\log_{10}P$	Y	x^2	xY	Y^2	Yc	Y-Yc=d	d^2
1	0.5	-0.3	97	0.09	-29.1	9409	93.63	3.37	11.36
2	1.0	0	100	0	0	10000	104.08	-4.08	16.65
3	1.2	0.08	100	0.0064	8	10000	106.87	-6.87	47.20
4	1.55	0.19	114	0.0361	21.66	12996	110.70	3.3	10.89
5	1.65	0.22	116	0.0484	25.52	13456	111.74	4.26	18.15
SUM		0.19	527	0.181	26.08	55861			104.24

Appendix 2.1

LINE OF REGRESSION AND STANDARD ERROR OF ESTIMATE IN THE BERETANIA AREA

$$Y = a + bx$$

$$\Sigma Y = N \cdot a + b\Sigma x$$

$$\Sigma xY = a\Sigma x + b\Sigma x^2$$

From Table 6

$$N = 4$$
$$\Sigma x = 0.18$$
$$\Sigma Y = 469$$
$$\Sigma xY = 22.9$$
$$\Sigma x^2 = 0.212$$

We have

$$469 = 4a + 0.18b \quad (1\text{-}1)$$

$$22.9 = 0.18a + 0.212b \quad (1\text{-}2)$$

From (1-1) and (1-2)

$$a = 116.85$$
$$b = 8.8$$

$$\therefore Y = 116.85 + 8.8x$$

x	Y
-0.3	114.21
0	116.85
0.18	118.43
0.3	119.49
0.4	120.37

$$Sy = \sqrt{20.63/4} = 2.27$$

Appendix 2.2

LINE OF REGRESSION AND STANDARD ERROR OF ESTIMATE IN THE KAIMUKI AREA

From Table 8

$$N = 5$$
$$\Sigma x = 0.58$$
$$\Sigma Y = 588$$
$$\Sigma xY = 74.9$$
$$\Sigma x^2 = 0.372$$

We get

$$588 = 5a + 0.58b \quad (2\text{-}1)$$
$$74.9 = 0.58a + 0.372b \quad (2\text{-}2)$$

From (2-1) and (2-2)

$$b = 21.96$$
$$a = 115.05$$

$$\therefore Y = 115.05 + 21.96x$$

x	Y
-0.3	108.46
0	115.05
0.18	119.01
0.3	121.64
0.4	123.84

$$Sy = \sqrt{113.64/5} = 4.77$$

Appendix 2.3

LINE OF REGRESSION AND STANDARD ERROR OF ESTIMATE IN THE MANOA AREA

From Table 7

$$N = 4$$
$$\Sigma x = 0.18$$
$$\Sigma Y = 457$$
$$\Sigma xY = 22.74$$
$$\Sigma x^2 = 0.212$$

We get

$$457 = 4a + 0.18b \quad (3\text{-}1)$$

$$22.74 = 0.18a + 0.212b \quad (3\text{-}2)$$

From (3-1) and (3-2)

$$b = 10.66$$
$$a = 113.77$$

$$\therefore Y = 113.77 + 10.66x$$

x	Y
-0.3	110.57
0	113.77
0.18	115.69
0.3	116.97

$$Sy = \sqrt{21.59/4} = 2.3$$

Appendix 2.4

LINE OF REGRESSION AND STANDARD ERROR OF ESTIMATE IN THE WAIKIKI AREA

From Table 9

$$N = 5$$
$$\Sigma x = 0.19$$
$$\Sigma xY = 26.08$$
$$\Sigma Y = 527$$
$$\Sigma x^2 = 0.181$$

We get

$$527 = 5a + 0.19b \quad (4\text{-}1)$$

$$26.08 = 0.19a + 0.181b \quad (4\text{-}2)$$

From (4-1) and (4-2)

$$b = 34.84$$

$$a = 104.08$$

$$\therefore Y = 104.08 + 34.84x$$

x	Y
-0.3	93.63
0	104.08
0.08	106.87
0.19	110.70
0.22	111.74

$$Sy = \sqrt{104.24/5} = 4.57$$

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1. Yoshihisa Okumura, Eiji Ohmori, Tomihiko Kawano, and Kaneharu Fukuda: "Field Strength and Its Variability in UHF and VHF Land-Mobile Radio Service," *Review of the Electrical Communication Laboratory*, Vol. 16, No. 9-10, September-October 1968.

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